

# Recent Landsat Calibration Activities

Landsat Science Team Meeting  
July 9, 2015  
USGS EROS

Dennis Helder  
And a cast of thousands!



# Outline

- Reflectance-based cross-calibration of Landsat archive
- Absolute Pseudo Invariant Calibration Site (A-PICS) Development
  - The infamous Algodones Dunes campaign

# **Update on Reflectance-based Cross-calibration of Landsat sensors**

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# Background

- The objective is to use Landsat 8 TOA reflectance calibration as the basis for calibration of the Landsat archive.
  - Landsat 8 is the best calibrated Landsat sensor to date and the general consensus is reflectance-based calibration is ‘better’ than radiance-based calibration
- The basic idea is to be able to generate the TOA reflectance from the Landsat products without using at-sensor radiance
- **Advantage:** This way minimizes uncertainties due to ESUN models
- The work also includes recalibrating some of the earlier Landsats and then tying them to a reflectance-based calibration of OLI.

# Procedure

- Non-coincident collects from Sonora and Lake Tahoe are primarily used as test sites.
- Some of the older Landsats do have near simultaneous image pairs.
  - Two-point cross-calibration approach using dark targets to complement the bright PICS
  - Started with L1T product, in at-sensor radiance units, then scale it by post launch gain in the CPF. Termed: **Artifact corrected DN** (*basically DN corrected for relative gain, bias subtraction, linear drift etc.*)
- Multiple ROIs selected from a given scene
- SBAF derived using Hyperion
- Linear regression is used to determine gain and bias
  - Statistical tests done to check the significance of bias.
- Validation using other sites.

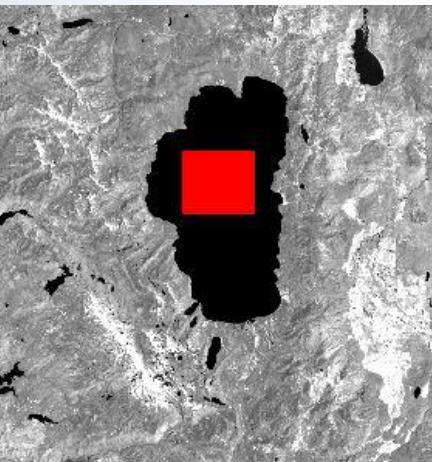
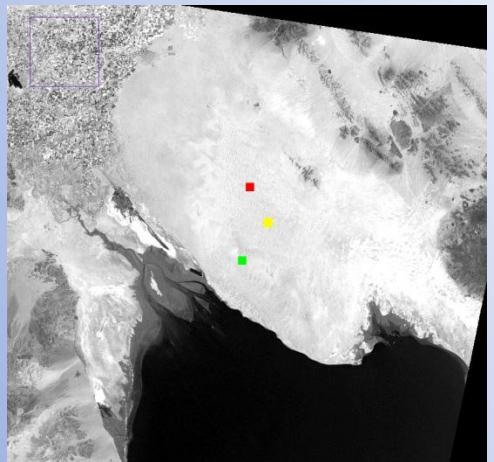
# Landsat 8 OLI to ETM+ Cross-Calibration : Basic Cal Equations to consider

Reflectance Cal Equation	$DN_{8,\lambda} = g_{8,\rho,\lambda} \cdot \rho'_{8,\lambda} + b_{8,\rho,\lambda}$	<p><math>\rho_{8,\lambda}</math>: Band Specific Reflectance as seen by L8 OLI</p> <p><math>g_{8,\rho,\lambda}</math>: Band Specific L8 OLI reflectance gain to convert from reflectance to DN</p> <p><math>b_{8,\rho,\lambda}</math>: Band Specific L8 OLI additive bias in DN</p>
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Landsat 7 ETM+ Cross calibration procedure

Reflectance Cal Equation to take reflectance from L8 to L7 DN	$DN_{7,\lambda} = g_{7,\rho,\lambda} * (SBAF_{\frac{7}{8},\rho,\lambda,ROI} * \rho'_{8,\lambda} * \frac{\cos(\alpha_7)}{\cos(\alpha_8)} * d^2_{L7}) + b_{7,\rho,\lambda}$	<p><math>DN_{7,\lambda}</math>: Artifact corrected DN</p> <p><math>\alpha</math>: Solar Zenith Angle</p>
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# Landsat 8 OLI to ETM+ Cross-Calibration



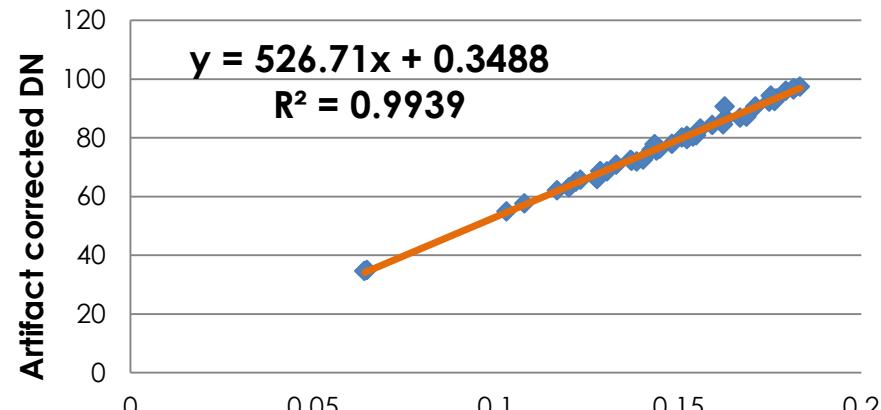
- eight pairs of near-coincident scenes from the Sonora Desert and four from lake Tahoe are selected.
- 5 ROI for each pair of Sonora desert and 1 ROI for Lake Tahoe is used

Scene Pair used	Total 7 ROIs
Scene Pair-1	LE70380382013120EDC00
	LC80380382013112LGN01
Scene Pair-2	LE70380382013136EDC00
	LC80380382013144LGN00
Scene Pair-3	LE70380382013152EDC00
	LC80380382013176LGN00
Scene Pair-4	LE70380382014075EDC00
	LC80380382014067LGN00
Scene Pair-5	LE70380382014235EDC00
	LC80380382014243LGN00
Scene Pair-6	LE70380382014267EDC00
	LC80380382014275LGN00
Scene Pair-7	LE70380382014283EDC00
	LC80380382014291LGN00
Scene Pair-8	LE70380382014315EDC00
	LC80380382014307LGN00
Scene Pair-9	LE70430332014174EDC00
	LC80430332014182LGN00
Scene Pair-10	LE70430332014190EDC02
	LC80430332014182LGN00

# Landsat 8 OLI to ETM+ Cross-Calibration

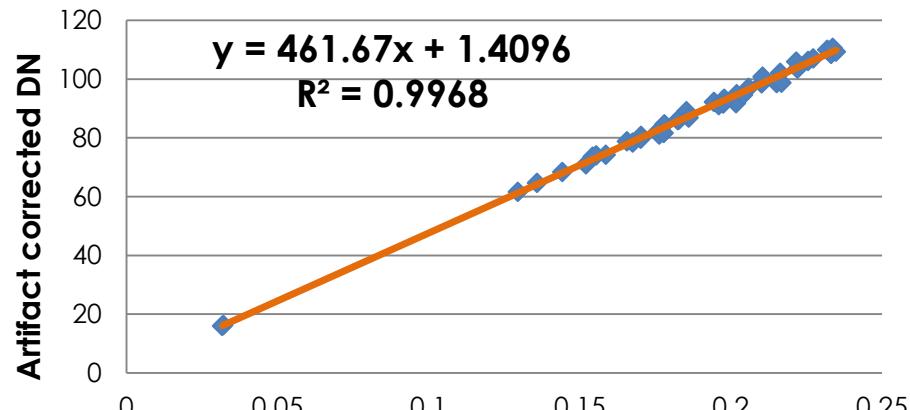
**Note:** Artifact Corrected DN=Landsat 7 radiance\* average of Detector Post launch Gain

Landsat 7 Vs Landsat 8 cross Calibration:Blue Band



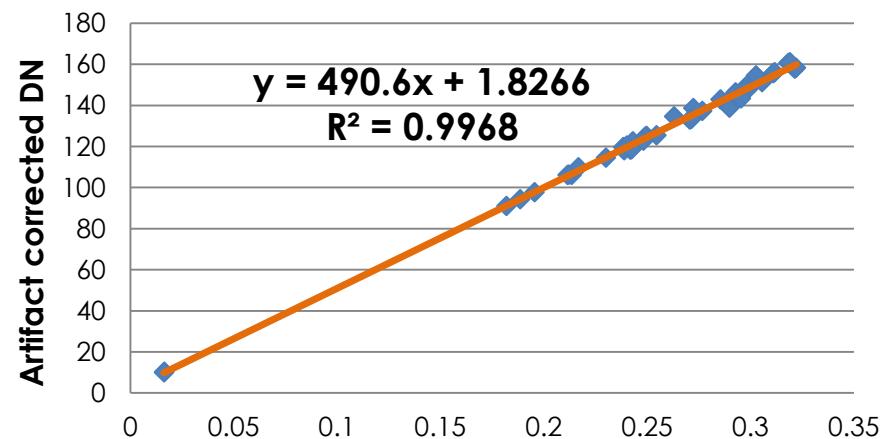
Landsat 8 OLI reflectance\*SBAF Landsat 8 to Landsat 7\* Cosine and Earth Sun Distance correction Factor

Landsat 7 Vs Landsat 8 cross Calibration:Green Band



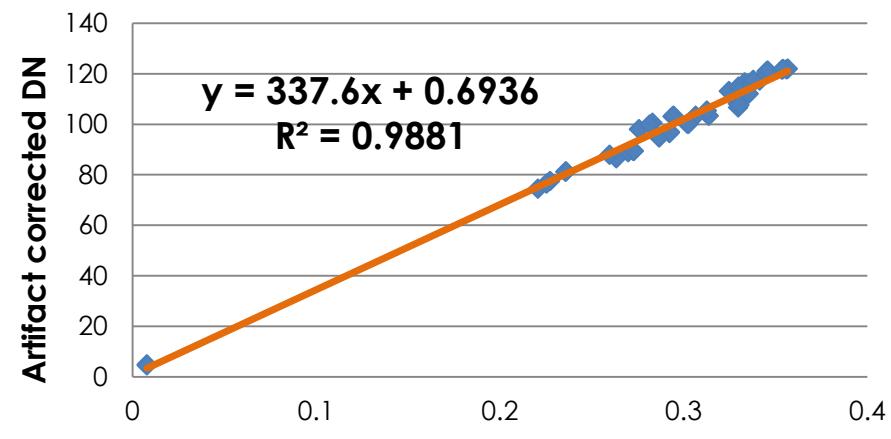
Landsat 8 OLI reflectance\*SBAF Landsat 8 to Landsat 7\* Cosine and Earth Sun Distance correction Factor

Landsat 7 Vs Landsat 8 cross Calibration:RED Band



Landsat 8 OLI reflectance\*SBAF Landsat 8 to Landsat 7\* Cosine and Earth Sun Distance correction Factor

Landsat 7 Vs Landsat 8 cross Calibration:NIR Band

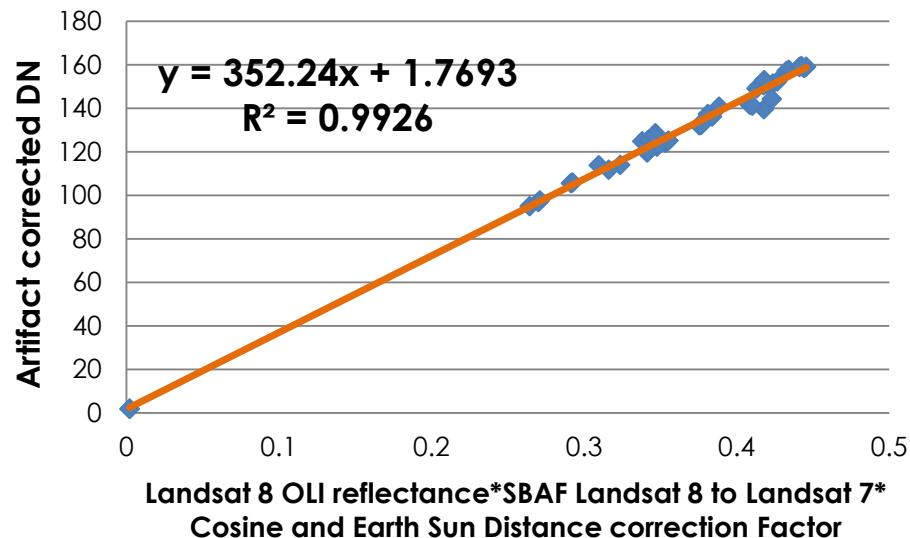


Landsat 8 OLI reflectance\*SBAF Landsat 8 to Landsat 7\* Cosine and Earth Sun Distance correction Factor

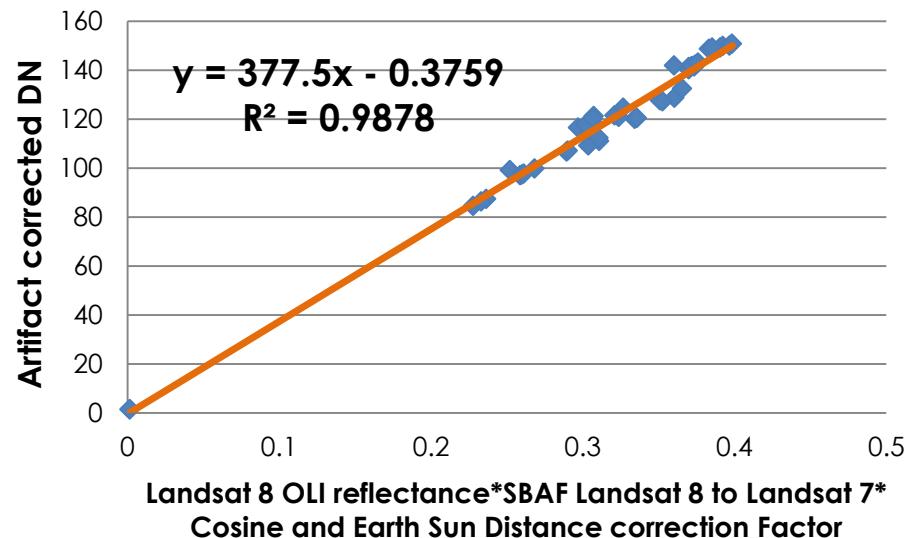
# Landsat 8 OLI to ETM+ Cross-Calibration

**Note:** Artifact Corrected DN=Landsat 7 radiance\* average of Detector Post launch Gain

Landsat 7 Vs Landsat 8 cross Calibration:SWIR 1 Band



Landsat 7 Vs Landsat 8 cross Calibration:SWIR 2 Band



# Statistical Test For Landsat 8 OLI to ETM+ Cross-Calibration

Null Hypothesis: Bias=0

Estimates of Band 1					Estimates of Band 2				
	Estimate	Std.Error	t value	Pr(> t )		Estimate	Std.Error	t value	Pr(> t )
(Intercept)	0.349	0.964	0.362	0.719	(Intercept)	1.410	0.785	1.796	0.080
Slope	526.714	6.500	81.033	<2e-16	Slope	461.670	4.157	111.068	<2e-16

Estimates of Band 3					Estimates of Band 4				
	Estimate	Std.Error	t value	Pr(> t )		Estimate	Std.Error	t value	Pr(> t )
(Intercept)	1.827	1.148	1.591	0.119	(Intercept)	0.694	1.745	0.397	0.693
Slope	490.600	4.387	111.830	<2e-16	Slope	337.600	5.864	57.575	<2e-16

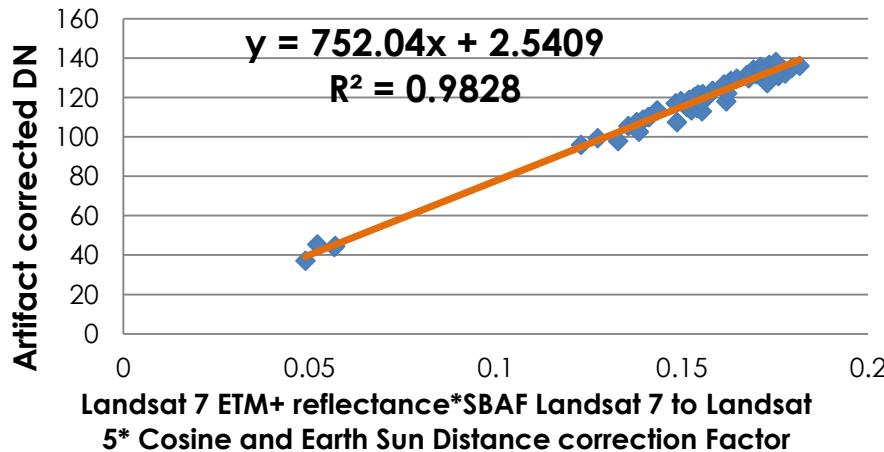
Estimates of Band 5					Estimates of Band 7				
	Estimate	Std.Error	t value	Pr(> t )		Estimate	Std.Error	t value	Pr(> t )
(Intercept)	1.769	1.774	0.997	0.325	(Intercept)	-0.376	2.133	-0.176	0.861
Slope	352.239	4.818	73.110	<2e-16	Slope	377.499	6.630	56.942	<2e-16

- From the statistical test, bias for all the band are found to be insignificant, hence the fitted line is passed through zero to find the gain for the model.

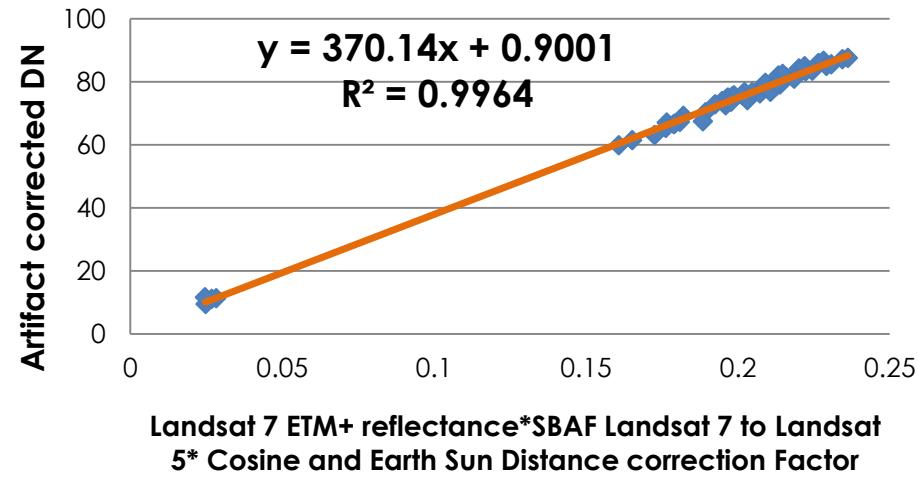
# Landsat 7 ETM+ to Landsat 5 TM Cross-Calibration

**Note:** Artifact Corrected DN =  $L_{5,\lambda} * (L_{5,\text{old gain}}(t) / L_{5,\text{new gain}}(t)) * L_{5,\text{Normalized gain}}$

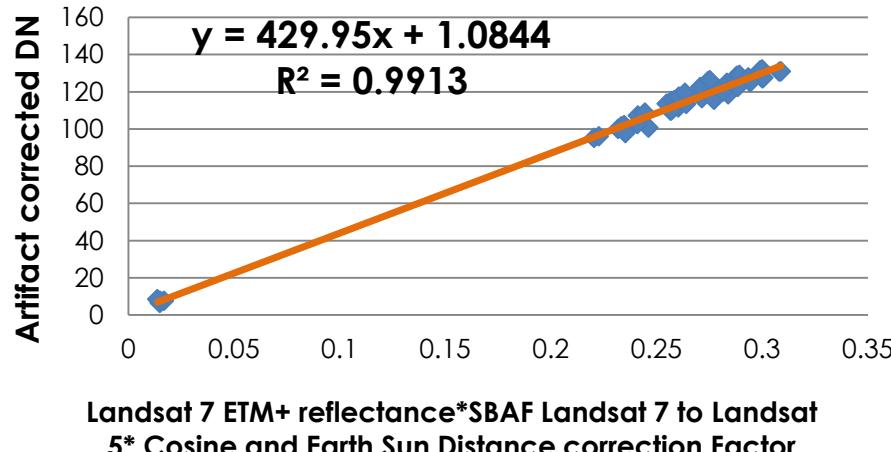
Landsat 5 Vs Landsat 7 cross Calibration:Blue Band



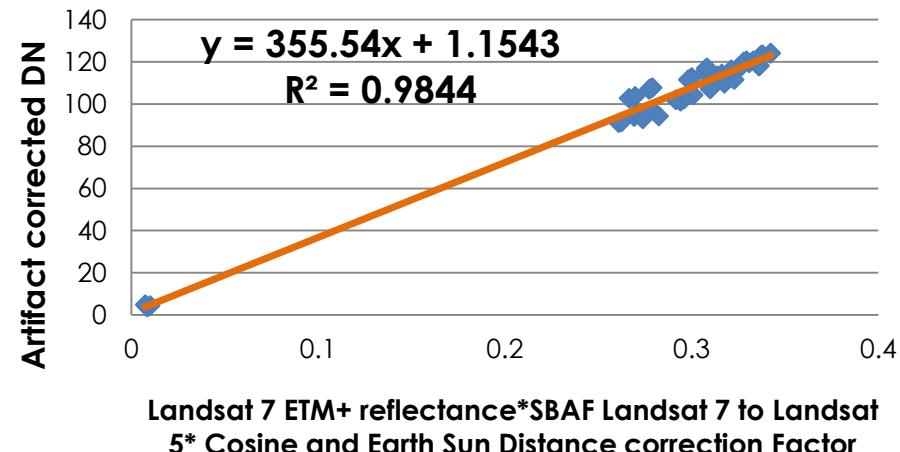
Landsat 5 Vs Landsat 7 cross Calibration:Green Band



Landsat 5 Vs Landsat 7 cross Calibration:RED Band



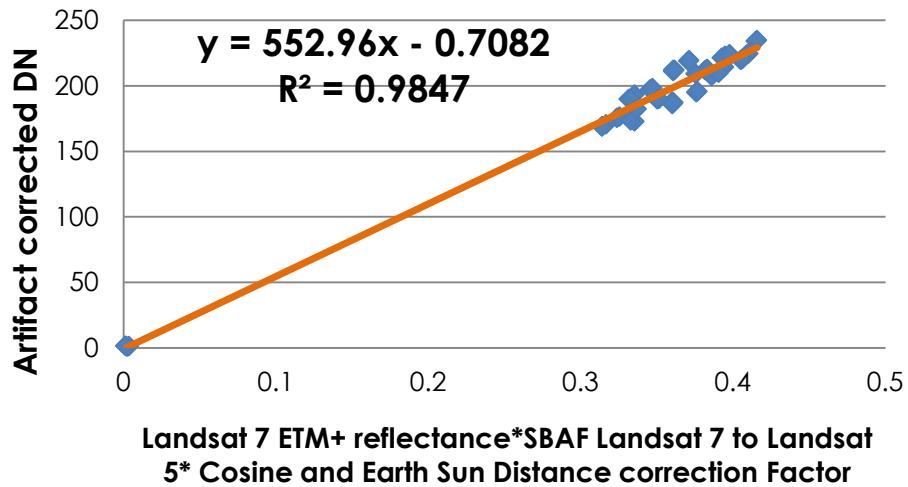
Landsat 5 Vs Landsat 7 cross Calibration:NIR Band



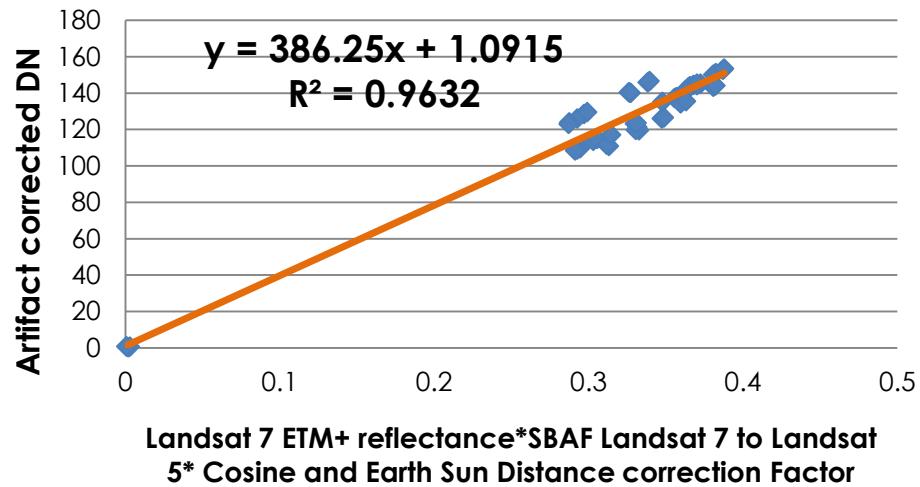
# Landsat 7 ETM+ to TM Cross-Calibration

**Note:** Artifact Corrected DN =  $L_{5,\lambda} * (L_{5,\text{old gain}}(t) / L_{5,\text{new gain}}(t)) * L_{5,\text{Normalized gain}}$

Landsat 5 Vs Landsat 7 cross Calibration:SWIR 1 Band



Landsat 5 Vs Landsat 7 cross Calibration:SWIR 2 Band



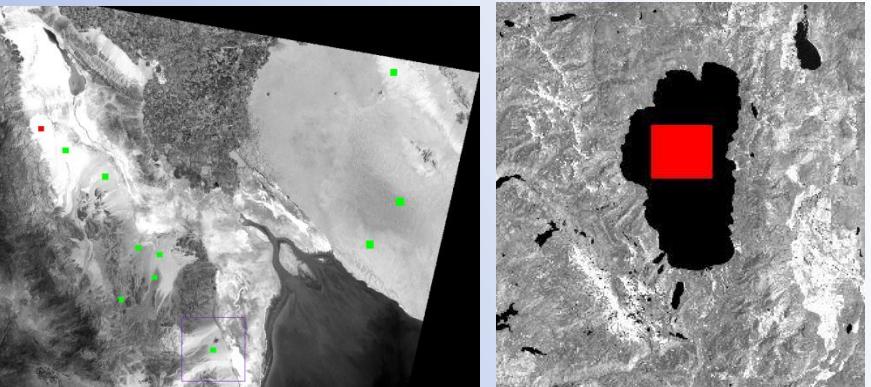
# Landsat 5 TM to Landsat 5 MSS Cross-Calibration

Reflectance Cal Equation	$\rho_{5,\lambda} = L_{5,\lambda} * (L_{5,\text{old gain}}(t) / L_{5,\text{new gain}}(t)) * L_{5,\text{Normalized gain}} / g_{5,\rho,\lambda}$	<p><math>\rho_{5,\lambda}</math>: Band Specific Reflectance as seen by L5 TM</p> <p><math>L_{5,\lambda}</math>: Band Specific radiance as seen by L5 TM</p> <p><math>g_{5,\rho,\lambda}</math>: Band Specific L5 TM reflectance gain to convert from reflectance to DN</p>
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Landsat 5 MSS Cross calibration procedure

Reflectance Cal Equation to take reflectance from L5TM to L5 MSS	$L'_{5\text{MSS},\lambda} = g_{5\text{mss},\rho,\lambda} * (\text{SBAF}_{\frac{5\text{MSS}}{5\text{TM}}} * \rho_{5,\lambda} * \frac{\mathbf{d}^2_{5\text{TM}}}{\mathbf{d}^2_{5\text{MSS}}} * \frac{\cos\alpha_{5\text{MSS}}}{\cos\alpha_{5\text{TM}}}) + b_{5\text{MSS},\rho,\lambda}$ $L'_{5\text{MSS},\lambda} = ((L_{5\text{MSS},\lambda} / g_{5\text{abs gain}} - \text{bias}) / (g_{5\text{crosscal}} * \text{TDF})) * L'_{5,\lambda}$ <p><math>L'_{5,\lambda}</math>: Archive Radiance</p>
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# Landsat 5 TM to 5 MSS Cross-Calibration



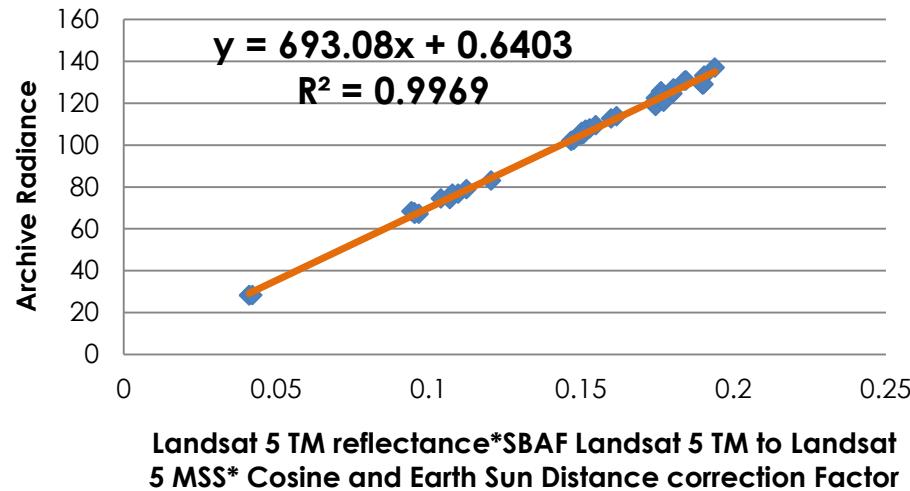
- Seven pairs of near-coincident scenes from the Sonora Desert and three from Lake Tahoe are selected.
- 5 ROI for each pair of Sonora Desert and 1 ROI for Lake Tahoe is used

Scene Pair used 5	Total 11 ROIs	
Scene Pair-1	LM50430331984180AAA03	1 sec apart
	LT50430331984180XXX16	
Scene Pair-2	LM50430331985214AAA03	1 sec apart
	LT50430331985214XXX05	
Scene Pair-3	LM50430331987188AAA03	1 sec apart
	LT50430331987188XXX02	
Scene Pair-4	LM50380381985275AAA03	1 sec apart
	LT50380381985275XXX04	
Scene Pair-5	LM50380381986326AAA03	1 sec apart
	LT50380381986326XXX04	
Scene Pair-6	LM50380381987281AAA03	1 sec apart
	LT50380381987281XXX03	
Scene Pair-7	LM50380381988204AAA03	1 sec apart
	LT50380381988204XXX03	
Scene Pair-8	LM50380381992199AAA03	1 sec apart
	LT50380381992199XXX02	
Scene Pair-9	LM50380381986358AAA03	1 sec apart
	LT50380381986358XXX03	
Scene Pair-10	LM50380381986166AAA03	1 sec apart
	LT50380381986166XXX03	

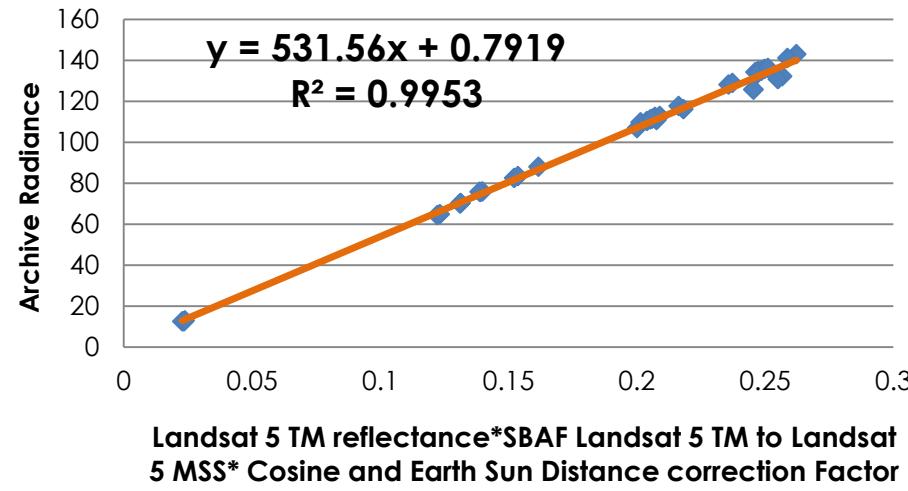
# Landsat 5 TM to 5 MSS Cross-Calibration

**Note:** Archive Radiance =  $(L_{5\text{MSS},\lambda}/g_{5\text{abs gain}} - \text{bias})/(g_{5\text{cross-cal}} * \text{TDF})$

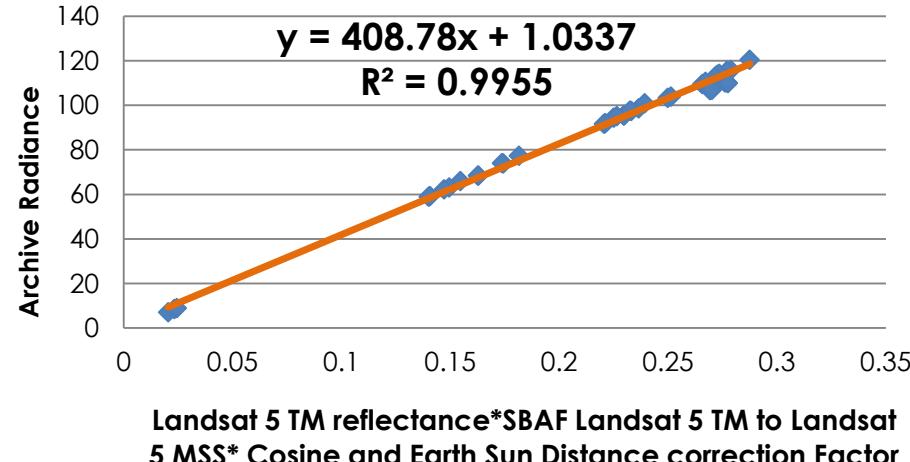
L-5 TM Vs L-5 MSS cross Calibration:Green Band



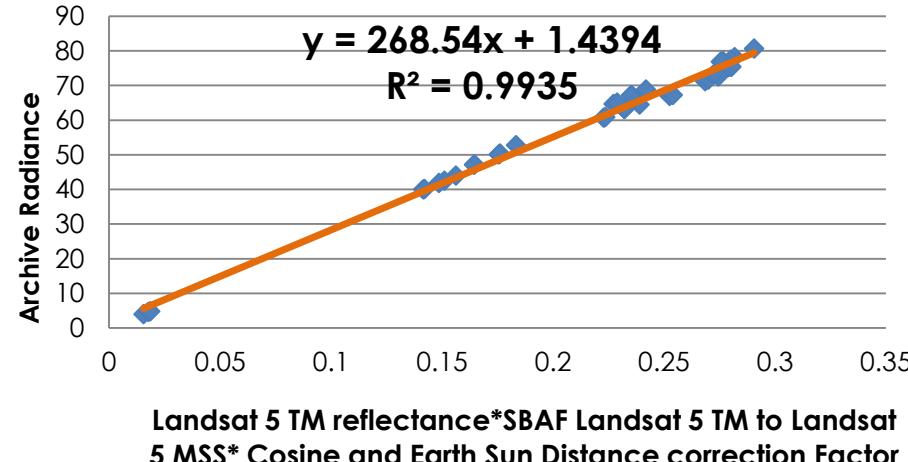
L-5 TM Vs L-5 MSS cross Calibration:RED Band



L-5 TM Vs L-5 MSS cross Calibration:NIR-1 Band



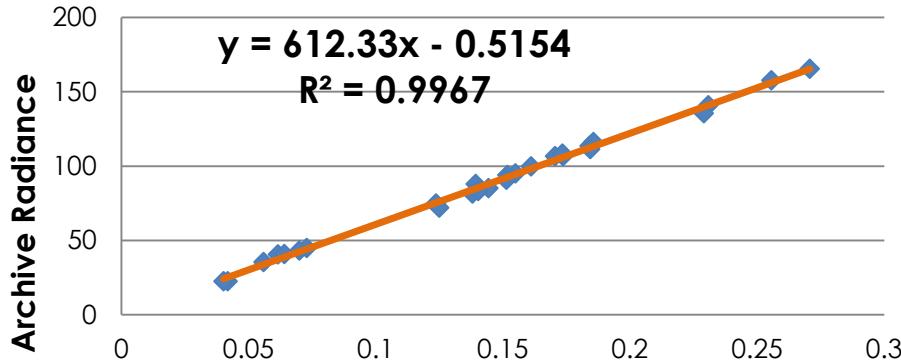
L-5 TM Vs L-5 MSS cross Calibration:NIR-2 Band



# Landsat 5 MSS to 4 MSS Cross-Calibration

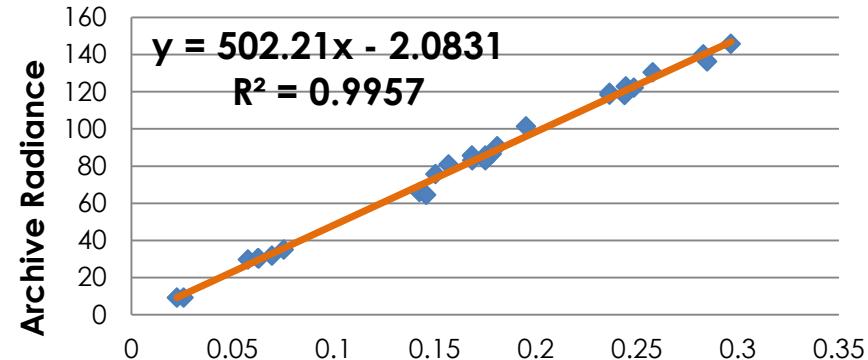
**Note:** : Archive Radiance =  $(L_{4\text{MSS},\lambda}/g_{4\text{abs gain}} - \text{bias})/(g_{4\text{cross-cal}} * \text{TDF})$

L-5 MSS Vs L-4 MSS cross Calibration:Green Band



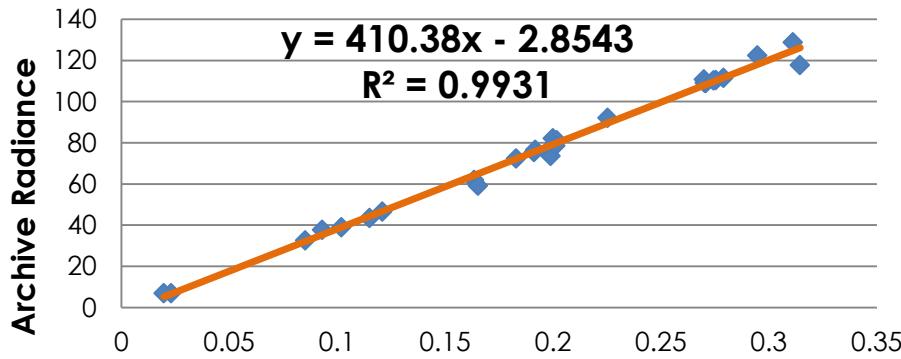
Landsat 5 MSS reflectance\*SBAF Landsat 5 MSS to Landsat 4 MSS\* Cosine and Earth Sun Distance correction Factor

L-5 MSS Vs L-4 MSS cross Calibration:RED Band



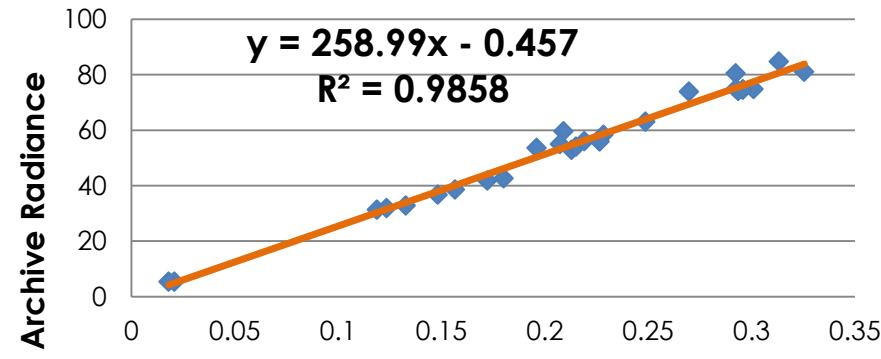
Landsat 5 MSS reflectance\*SBAF Landsat 5 MSS to Landsat 4 MSS\* Cosine and Earth Sun Distance correction Factor

L-5 MSS Vs L-4 MSS cross Calibration:NIR-1 Band



Landsat 5 MSS reflectance\*SBAF Landsat 5 MSS to Landsat 4 MSS\* Cosine and Earth Sun Distance correction Factor

L-5 MSS Vs L-4 MSS cross Calibration:NIR-2 Band

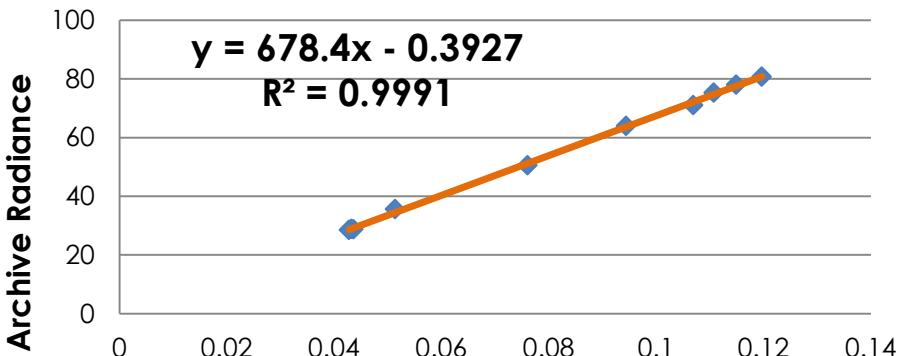


Landsat 5 MSS reflectance\*SBAF Landsat 5 MSS to Landsat 4 MSS\* Cosine and Earth Sun Distance correction Factor

# Landsat 4 MSS to 3 MSS Cross-Calibration

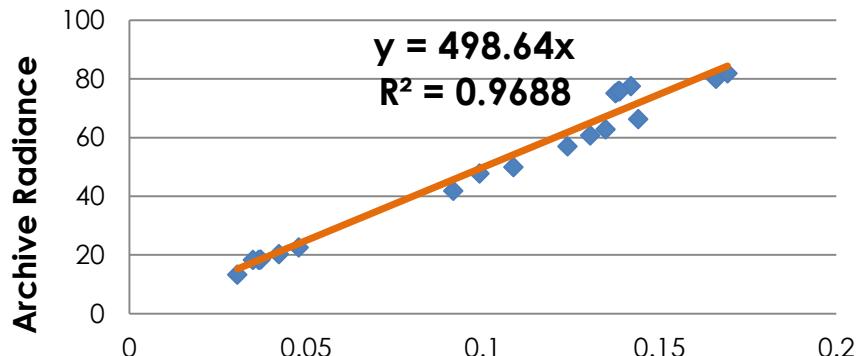
**Note:** : Archive Radiance =  $(L_{3\text{MSS},\lambda}/g_{3\text{abs gain}} - \text{bias})/(g_{3\text{cross cal}} * \text{TDF})$

L-4 MSS Vs L-3 MSS cross Calibration:Green Band



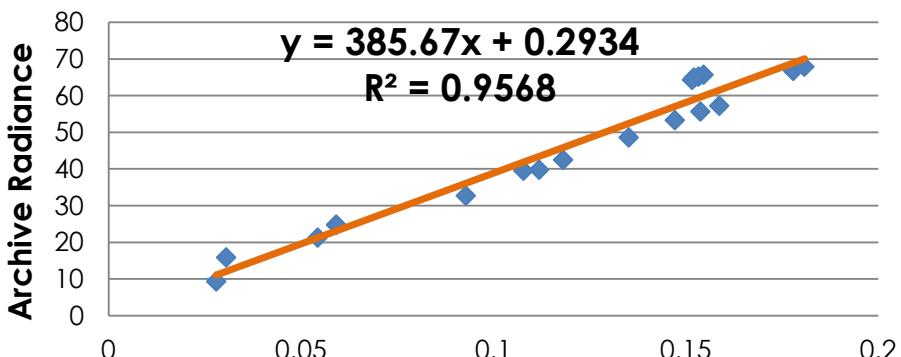
Landsat 4 MSS reflectance\*SBAF Landsat 4 MSS to Landsat 3 MSS\* Cosine and Earth Sun Distance correction Factor

L-4 MSS Vs L-3 MSS cross Calibration:RED Band



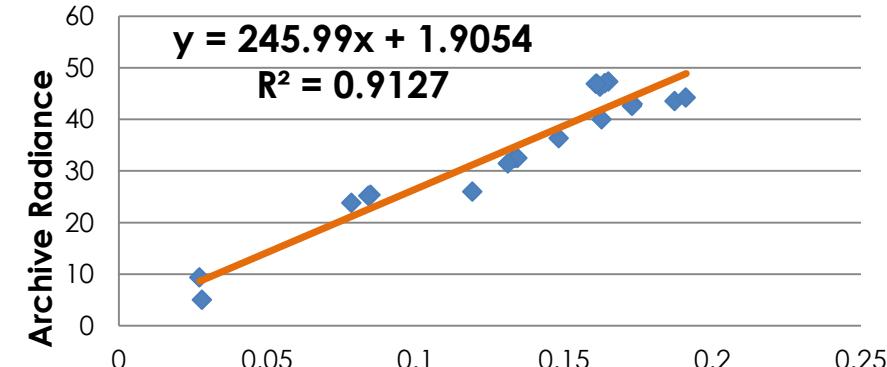
Landsat 4 MSS reflectance\*SBAF Landsat 4 MSS to Landsat 3 MSS\* Cosine and Earth Sun Distance correction Factor

L-4 MSS Vs L-3 MSS cross Calibration:NIR-1 Band



Landsat 4 MSS reflectance\*SBAF Landsat 4 MSS to Landsat 3 MSS\* Cosine and Earth Sun Distance correction Factor

L-4 MSS Vs L-3 MSS cross Calibration:NIR-2 Band



Landsat 4 MSS reflectance\*SBAF Landsat 4 MSS to Landsat 3 MSS\* Cosine and Earth Sun Distance correction Factor

# Validation: Algodones Dunes

How are the trends generated?

$$\rho_{8,\lambda} = (\mathbf{M}_{8,\rho,\lambda}^* \mathbf{DN}_{8,\lambda} + \mathbf{A}_{8,\rho,\lambda}) / \cos\alpha_8$$

$$\rho_{7,\lambda} = (L_{7,\lambda} * L_{7,\text{averaged post launch gain}} / g_{7,L,\lambda})^* \frac{d^2 7}{\cos\alpha_7}$$

$$\rho_{5,\lambda} = ((L_{5,\lambda} * (L_{5,\text{old gain}}(t) / L_{5,\text{new gain}}(t))^* L_{5,\text{Normalized gain}}) / g_{5,L,\lambda})^* \frac{d^2 5}{\cos\alpha_5}$$

$$\rho_{5MSS,\lambda} = ((L_{5MSS,\lambda} / g_{5abs \text{ gain}} - \text{bias}) / (g_{5cross \text{ cal}} * \text{TDF})) / g_{5MSS,L,\lambda}^* \frac{d^2 5MSS}{\cos\alpha_5 MSS}$$

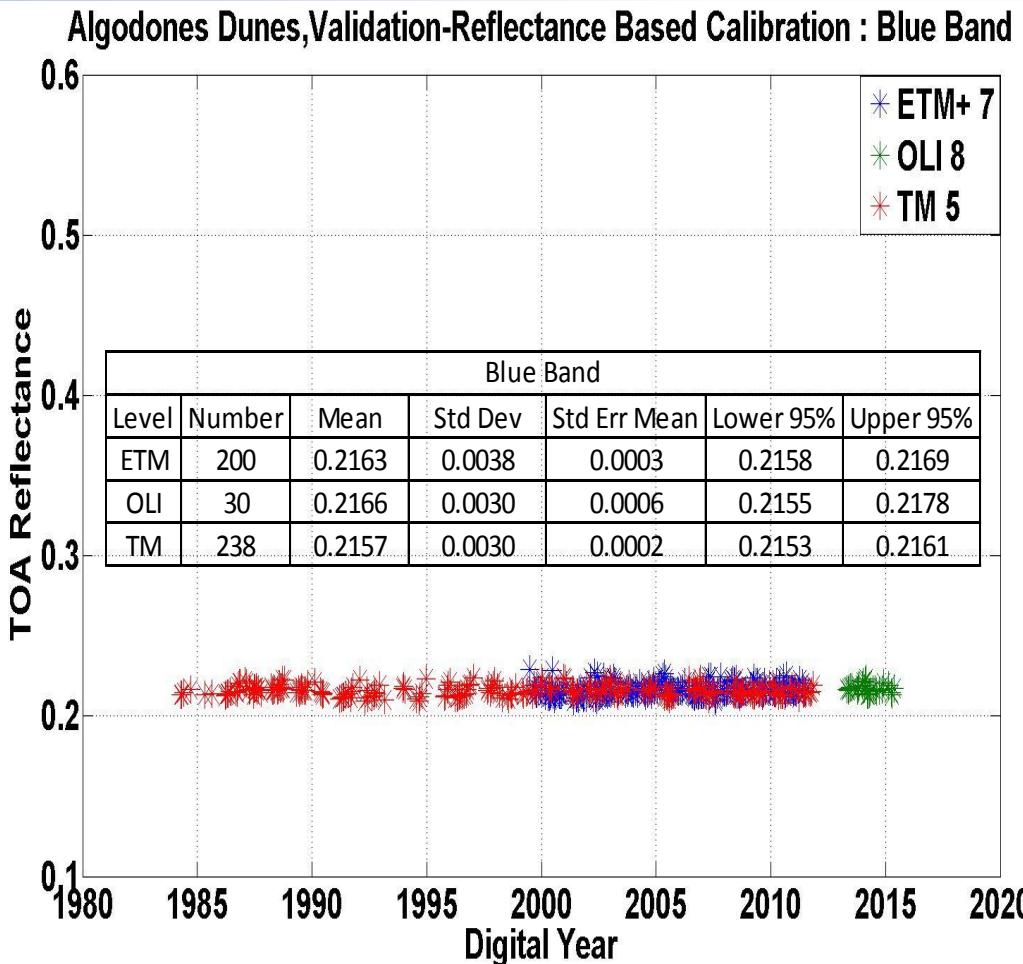
$$\rho_{4MSS,\lambda} = ((L_{4MSS,\lambda} / g_{4abs \text{ gain}} - \text{bias}) / (g_{4cross \text{ cal}} * \text{TDF})) / g_{4MSS,L,\lambda}^* \frac{d^2 4MSS}{\cos\alpha_4 MSS}$$

$$\rho_{3MSS,\lambda} = ((L_{3MSS,\lambda} / g_{3abs \text{ gain}} - \text{bias}) / (g_{3cross \text{ cal}} * \text{TDF})) / g_{3MSS,L,\lambda}^* \frac{d^2 3MSS}{\cos\alpha_3 MSS}$$

Y-axis:  $\rho_{8,\lambda}$  ,  $(SBAF_{\frac{8}{7}} * \rho_{7,\lambda})$  ,  $(SBAF_{\frac{8}{5}} * \rho_{5,\lambda})$  ,  $(SBAF_{\frac{8}{5MSS}} * \rho_{5MSS,\lambda})$  ,  $(SBAF_{\frac{8}{4MSS}} * \rho_{4MSS,\lambda})$  ,  $(SBAF_{\frac{8}{3MSS}} * \rho_{3MSS,\lambda})$

Gains When forced through 0, g(n,L,λ)						
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Landsat 8-7	529.02	468.93	497.36	339.86	356.88	376.37
Landsat 7-5	783.37	378.51	442.05	366.11	555.81	399.16
Landsat 5-5 MSS	697.18	535.25	413.17	274.58	NA	NA
Landsat 5 MSS -4 MSS	609.32	492.15	397.9	257.1	NA	NA
Landsat 4 MSS -3 MSS	674.86	498.64	387.79	258.66	NA	NA

# Validation: Algodones Dunes



## Statistical Test

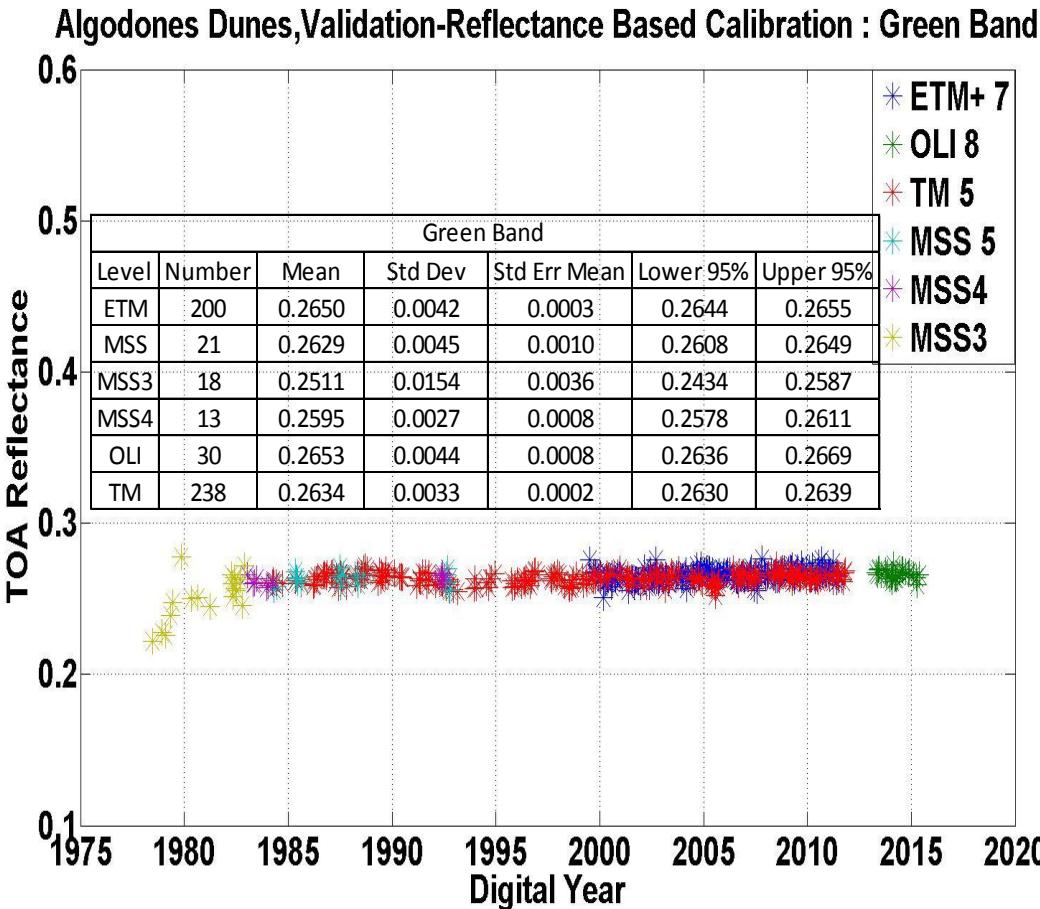
Null Hypothesis:  $\mu_1 = \mu_2$

Alternative Hypothesis:  $\mu_1 \neq \mu_2$

Level of significance = 95%

Blue Band				
Level	- Level	Difference	Std Err Dif	p-Value
OLI	TM	0.0010	0.0007	0.3046
ETM	TM	0.0007	0.0003	0.0993
OLI	ETM	0.0003	0.0007	0.8951

# Validation: Algodones Dunes



## Statistical Test

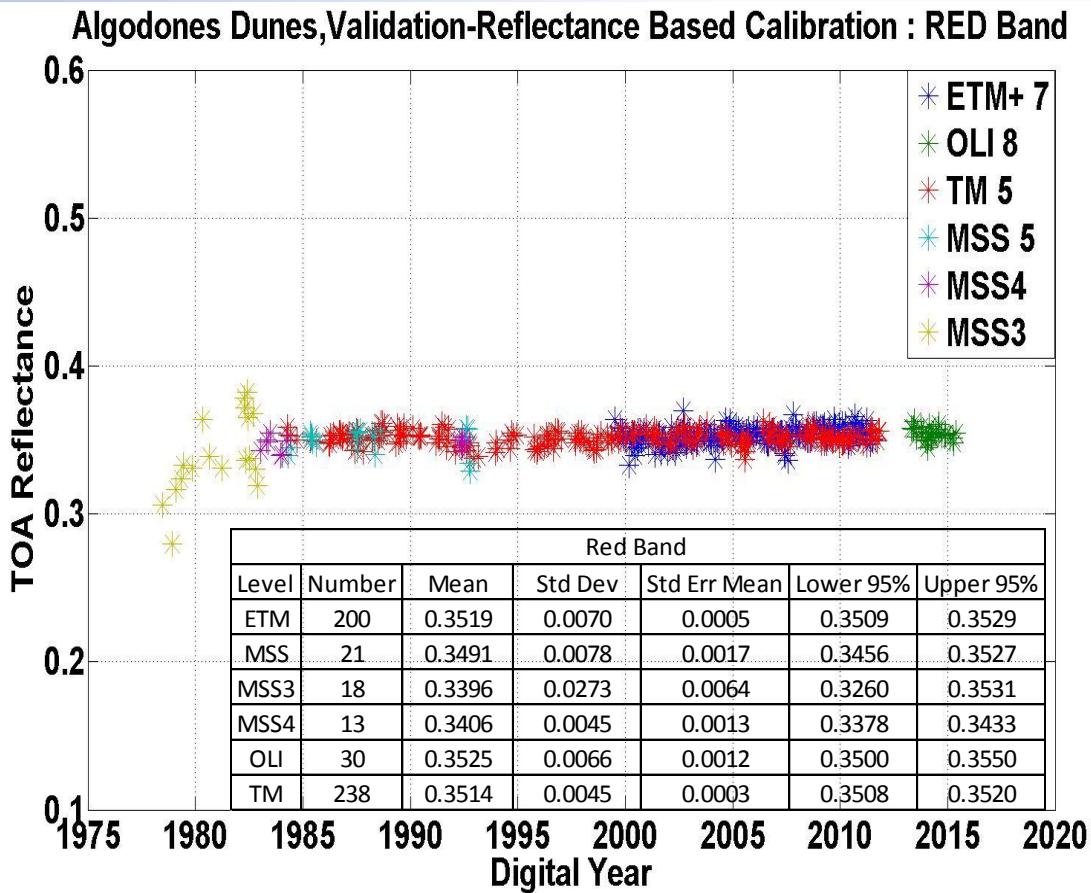
Null Hypothesis:  $\mu_1 = \mu_2$

Alternative Hypothesis:  $\mu_1 \neq \mu_2$

Level of significance = 95%

Green Band				
Level	- Level	Difference	Std Err Dif	p-Value
OLI	MSS3	0.0142167	0.0013893	<.0001
ETM	MSS3	0.0139013	0.0011467	<.0001
TM	MSS3	0.0123901	0.0011391	<.0001
MSS	MSS3	0.0118014	0.0014968	<.0001
MSS4	MSS3	0.0084235	0.0016961	<.0001
OLI	MSS4	0.0057932	0.0015473	0.0028
ETM	MSS4	0.0054778	0.0013338	0.0007
TM	MSS4	0.0039666	0.0013273	0.0347
MSS	MSS4	0.003378	0.0016445	0.3134
OLI	MSS	0.0024152	0.0013258	0.4526
ETM	MSS	0.0020999	0.0010689	0.3643
OLI	TM	0.0018266	0.0009028	0.3305
ETM	TM	0.0015112	0.000447	0.0101
TM	MSS	0.0005886	0.0010608	0.9937
OLI	ETM	0.0003153	0.0009124	0.9993

# Validation: Algodones Dunes



## Statistical Test

Null Hypothesis:  $\mu_1 = \mu_2$

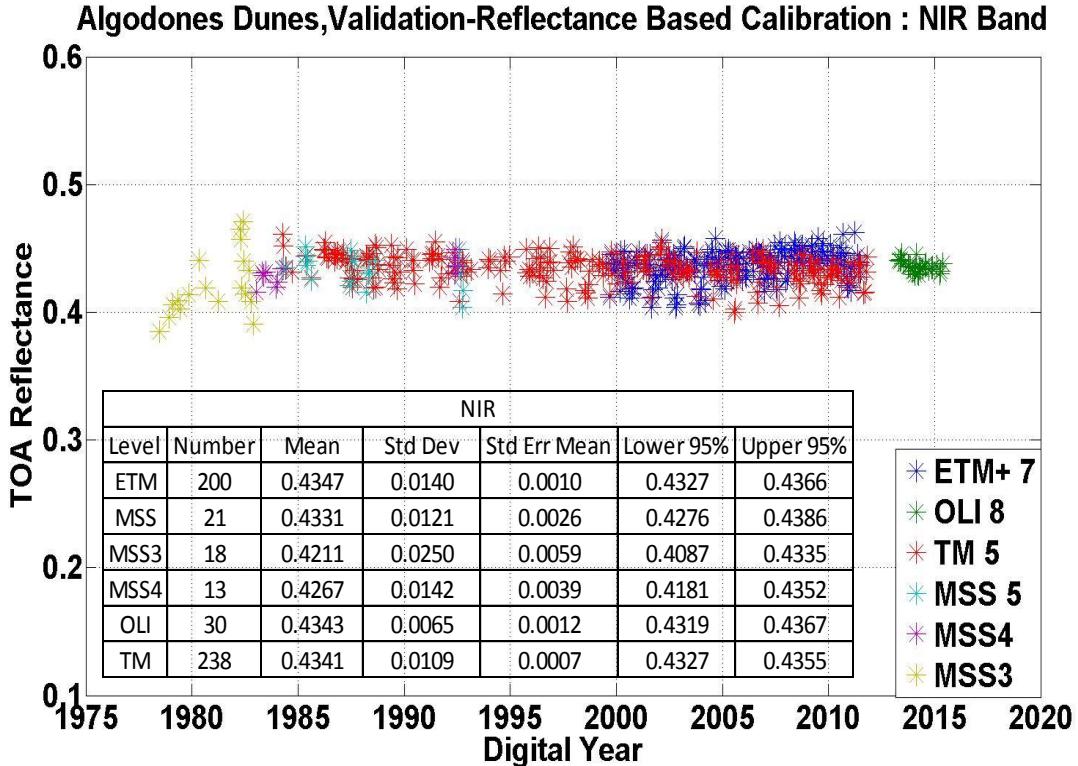
Alternative Hypothesis:  $\mu_1 \neq \mu_2$

Level of significance = 95%

Red Band				
Level	- Level	Difference	Std Err Dif	p-Value
MSS	MSS3	0.0096	0.0024	0.0015
MSS	MSS4	0.0085	0.0027	0.0194
ETM	MSS	0.0028	0.0017	0.6147
OLI	MSS	0.0033	0.0022	0.6366
TM	MSS	0.0023	0.0017	0.7794
OLI	TM	0.0011	0.0015	0.9787
ETM	TM	0.0005	0.0007	0.9861
OLI	ETM	0.0006	0.0015	0.9988
MSS4	MSS3	0.0010	0.0028	0.9991
OLI	MSS3	0.0129	0.0023	<.0001
ETM	MSS3	0.0123	0.0019	<.0001
TM	MSS3	0.0118	0.0019	<.0001
OLI	MSS4	0.0119	0.0025	<.0001
ETM	MSS4	0.0113	0.0022	<.0001
TM	MSS4	0.0108	0.0022	<.0001

# Validation: Algodones Dunes

Note: This is 'Red Edge' band for MSS



## Statistical Test

Null Hypothesis:  $\mu_1 = \mu_2$

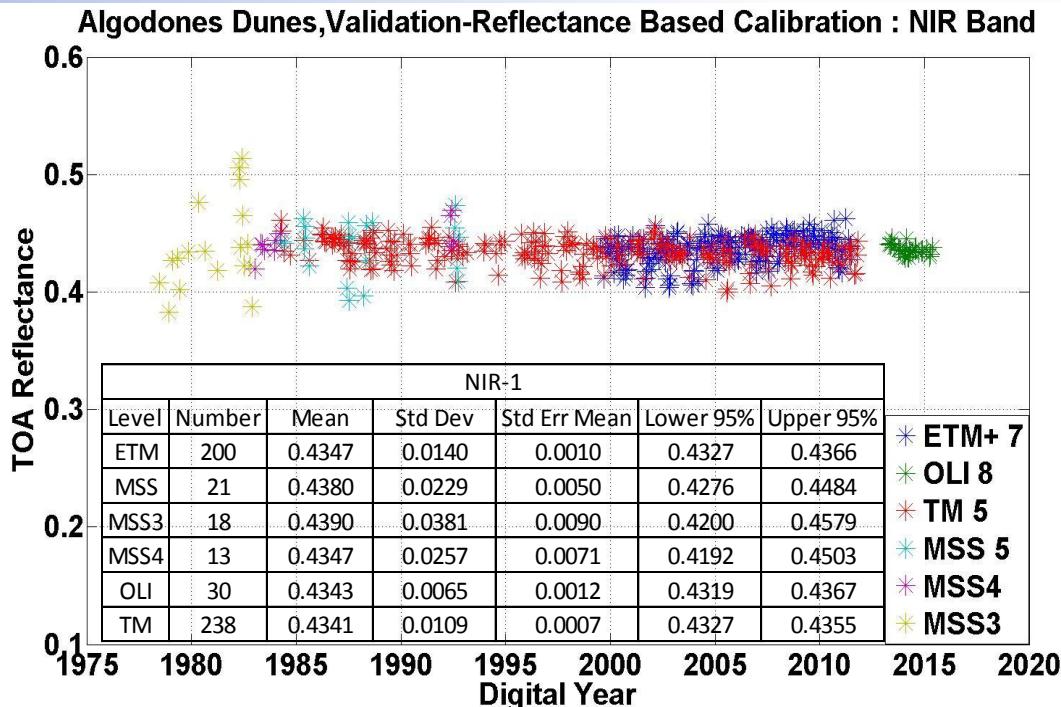
Alternative Hypothesis:  $\mu_1 \neq \mu_2$

Level of significance = 95%

NIR				
Level	- Level	Difference	Std Err Diff	p-Value
ETM	MSS3	0.0136	0.0032	0.0003
OLI	MSS3	0.0132	0.0038	0.0078
TM	MSS3	0.0130	0.0031	0.0006
MSS	MSS3	0.0120	0.0041	0.0418
ETM	MSS4	0.0080	0.0037	0.2530
OLI	MSS4	0.0076	0.0043	0.4757
TM	MSS4	0.0074	0.0037	0.3279
MSS	MSS4	0.0064	0.0045	0.7130
MSS4	MSS3	0.0056	0.0047	0.8366
ETM	MSS	0.0015	0.0029	0.9954
OLI	MSS	0.0012	0.0036	0.9996
TM	MSS	0.0010	0.0029	0.9995
ETM	TM	0.0006	0.0012	0.9975
ETM	OLI	0.0004	0.0025	1.0000
OLI	TM	0.0002	0.0025	1.0000

# Validation: Algodones Dunes

Note: This is the NIR band for MSS



## Statistical Test

Null Hypothesis:  $\mu_1 = \mu_2$

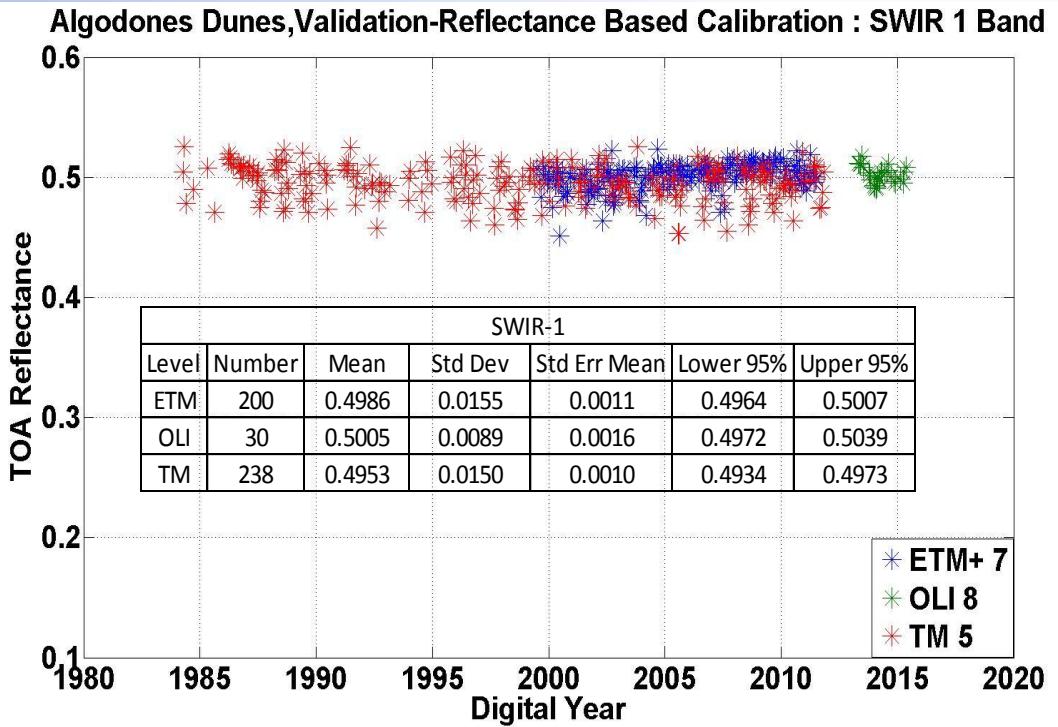
Alternative Hypothesis:  $\mu_1 \neq \mu_2$

Level of significance = 95%

NIR				
Level	- Level	Difference	Std Err Dif	p-Value
MSS3	TM	0.0049	0.0036	0.7544
MSS3	OLI	0.0047	0.0044	0.8950
MSS3	ETM	0.0043	0.0036	0.8417
MSS3	MSS4	0.0042	0.0054	0.9697
MSS	TM	0.0039	0.0034	0.8547
MSS	OLI	0.0037	0.0042	0.9507
MSS	ETM	0.0033	0.0034	0.9222
MSS	MSS4	0.0032	0.0052	0.9893
MSS3	MSS	0.0010	0.0047	0.9999
MSS4	TM	0.0007	0.0042	1.0000
ETM	TM	0.0006	0.0014	0.9987
MSS4	OLI	0.0005	0.0049	1.0000
ETM	OLI	0.0004	0.0029	1.0000
OLI	TM	0.0002	0.0029	1.0000
MSS4	ETM	0.0001	0.0042	1.0000

- OLI, ETM+, TM values remain same as previous plot.
- Only values for MSS are changed.

# Validation: Algodones Dunes



## Statistical Test

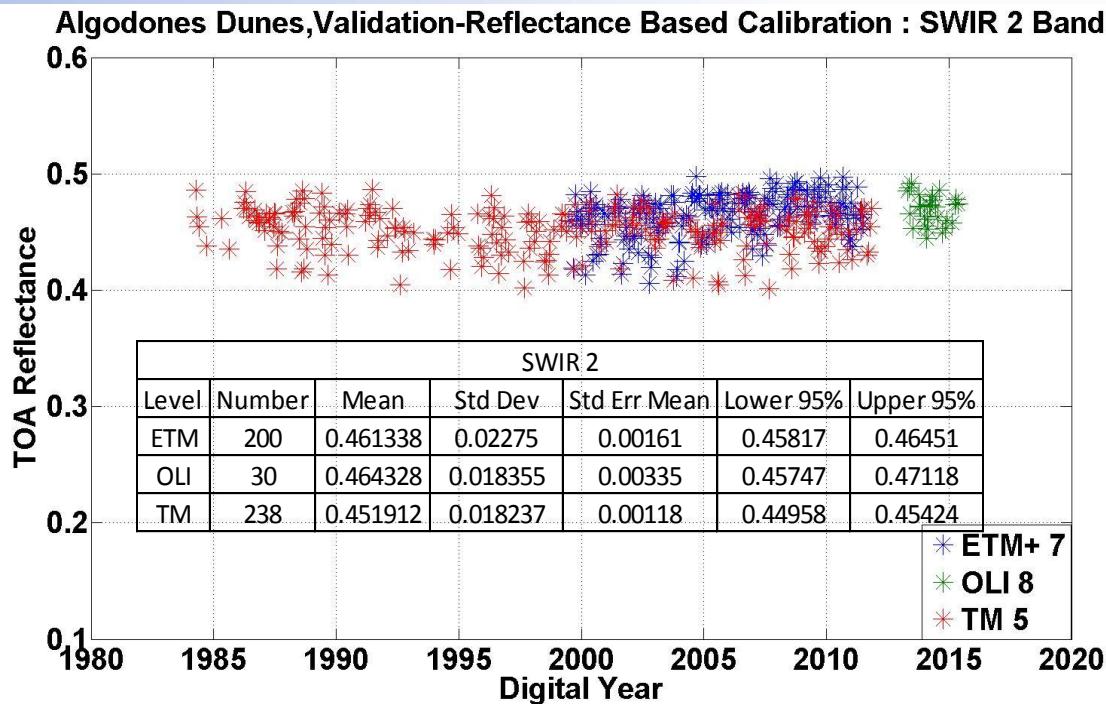
Null Hypothesis:  $\mu_1 = \mu_2$

Alternative Hypothesis:  $\mu_1 \neq \mu_2$

Level of significance = 95%

SWIR-1				
Level	- Level	Difference	Std Err Dif	p-Value
OLI	TM	0.005214	0.0028943	0.1702
ETM	TM	0.0032403	0.001433	0.0624
OLI	ETM	0.0019737	0.0029249	0.7783

# Validation: Algodones Dunes



## Statistical Test

Null Hypothesis:  $\mu_1 = \mu_2$

Alternative Hypothesis:  $\mu_1 \neq \mu_2$

Level of significance = 95%

SWIR 2				
Level	- Level	Difference	Std Err Dif	p-Value
OLI	TM	0.0124	0.0039	0.0048
ETM	TM	0.0094	0.0019	<.0001
OLI	ETM	0.0030	0.0040	0.7324

# Conclusion – Part 1

- Landsat archive reflectance-based cross-calibration approach looking solid.
- Cross-calibration connection from Landsat 8 OLI back to Landsat 3 MSS sensors was performed.
- Validation done at Algodones Dunes shows consistent result through Landsat 4 MSS.

## Future Work

- Analysis of Landsat 3 anomaly.
- Cross-calibration of remaining Landsats.
- Uncertainty Analysis

# Absolute Pseudo Invariant Calibration (A-PICS)

Story of SMACAA / Algodones Dunes - Validation / Comparison / Update

Larry Leigh

Calvin Kielas-Jensen

Mahesh Shrestha



South Dakota State University  
Image Processing Lab

# Overview A-PICS

- The desire is to transform relative calibration, using PICS sites, into absolute; thus, any sensor can fly over the site and an absolute radiance / reflectance can be predicted.
  - Two key components need to be understood to make this happen
    - Atmosphere
    - Ground reflectance / Bi-Directional Reflectance Distribution (BRDF)
- These two areas have been worked from each end and are meeting in the middle, this talk will present how this data / analysis is meeting in the middle to create a validated end-to-end model

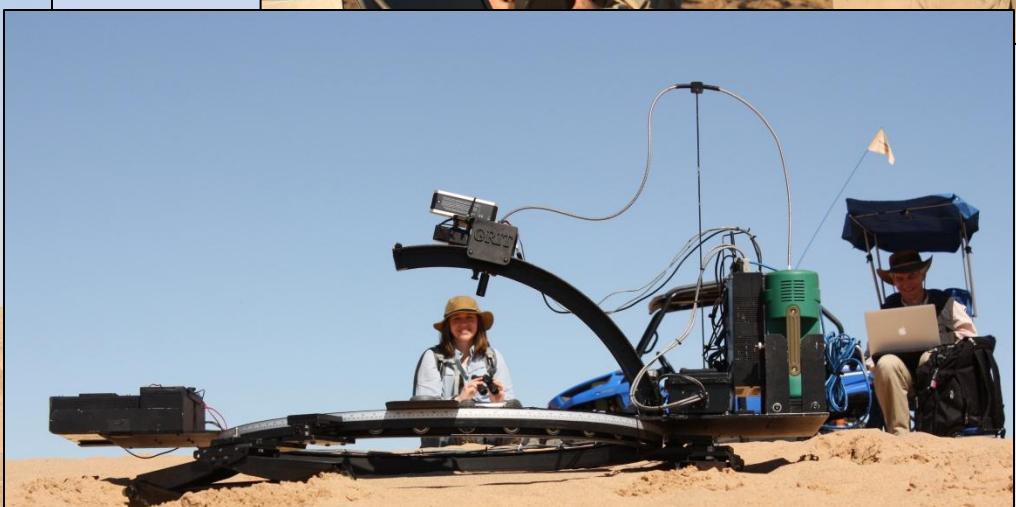
# A-PICS Ground Side: Algodones Dune Overview / Status

- March 8 – 14<sup>th</sup> Trip to Algodones dunes to acquire validation / model data of the surface reflectance and its BRDF
- SDSU activities:
  - In-field spectral data has been processed for several of the desert field sites
  - Atmospheric data processed
  - Sand samples acquired over a larger area of interest are being processed to validate in-situ measurements and determine area variation

# Where is Algodones Dunes?

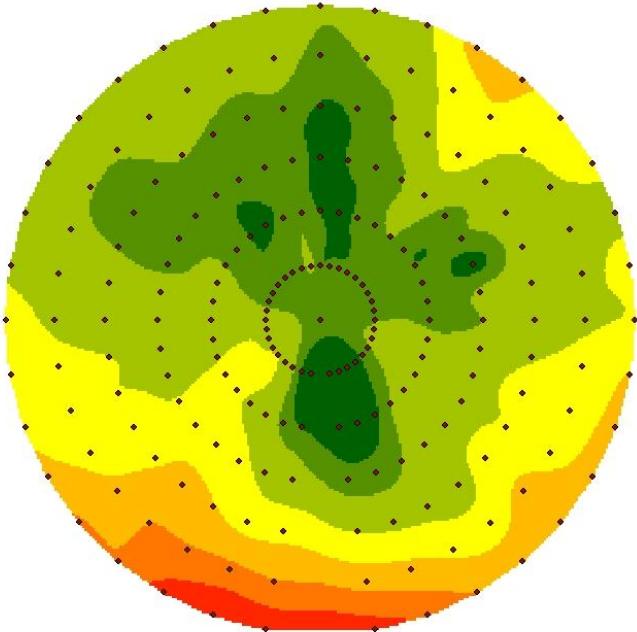


# Algodones Dunes, March 2015



# Initial Algodone Dunes BRDF Estimates

Craig Coburn, University of Lethbridge



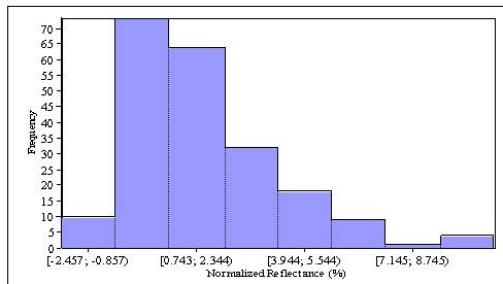
## Legend

• XYout

**600nm**

**Normalized Reflectance (%)**

- -2.552 - -0.5
- -0.5 - 0.5
- 0.5 - 2.5
- 2.5 - 4.5
- 4.5 - 6.5
- 6.5 - 8.5
- 8.5 - 10.5



Azimuth Resolution - 10 degrees (0-350)  
Zenith Resolution - 5 degrees (0-30)

BRDF Plot for mar10\_2015-17-44 at 600nm  
Normalized to Nadir and rotated

# A-PICS Atmospheric Side: SMACAA Overview / Status

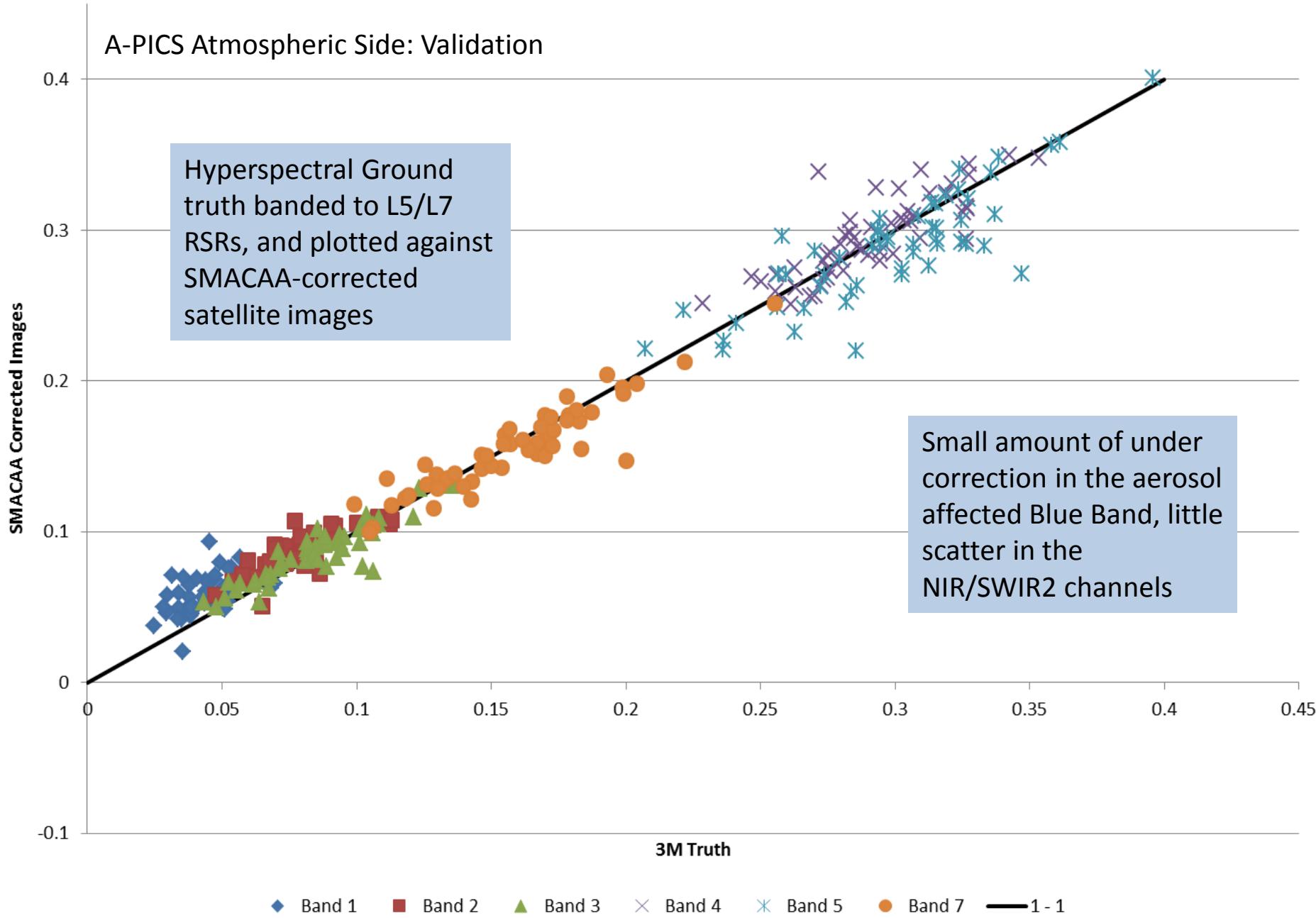
- SDSU Modtran Atmospheric Correction Anytime Anywhere (SMACAA) consists of two major components
  - SMACAA DB
  - SMACAA system which links images / DB / MODTRAN
- Database is operational and being regularly updated and data tier-ing is active to select from multiple data sources.
- Major update to Modtran 5.3.3, this version of MODTRAN added a number of output “streams” that allowed for a much more robust correction.
- Image ingest system is fully configured to accept any image from any sensor, is automated in house to ingest Landsat MSS/TM/ETM/OLI, Hyperion, etc.

# A-PICS Atmospheric Side: Validation - Dark Site

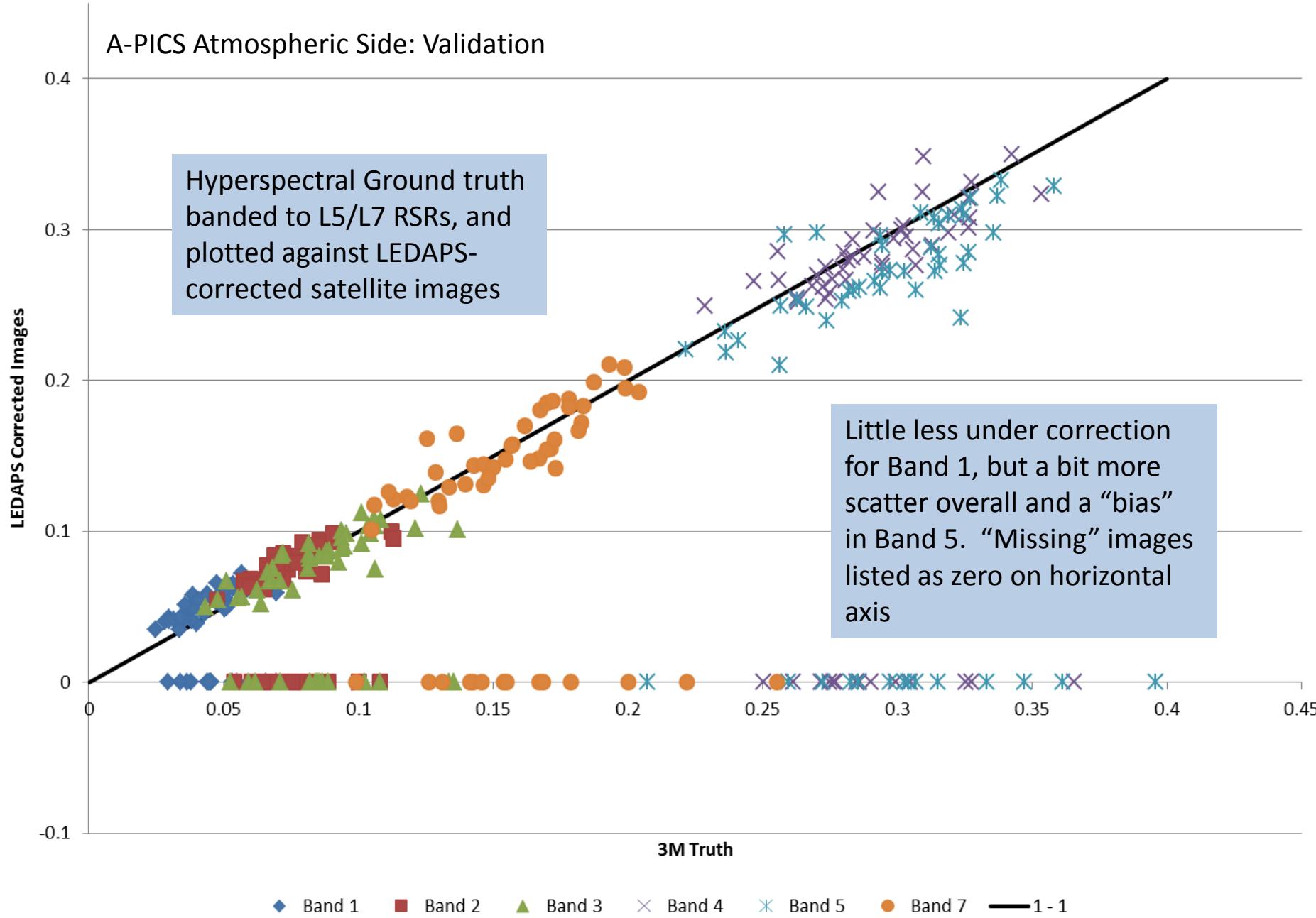
## SMACAA & L1T Surface Reflectance Product versus ground truth @ SDSU Test Site

- Comparison of SMACAA and L1T SR product to ground truth was performed using the SDSU Test site
  - Compare the capability to a “known” correction
  - Validate the atmospheric understanding for a known site.
- Ground truth comprised 63 field hyperspectral reflectance measurement sets covering the summer months for the years of 2004 – 2014; these include L5, L7 and L8 acquisitions.
  - L1T Images were collected for the 63 dates, and processed with SMACAA,
  - 41 L1T surface reflectance images collected and ROIs extracted
    - Only 41 of the 63 L1T SR scenes were available; it is unknown why the other 22 images were not available.

# SMACAA vs Truth (3M Site)

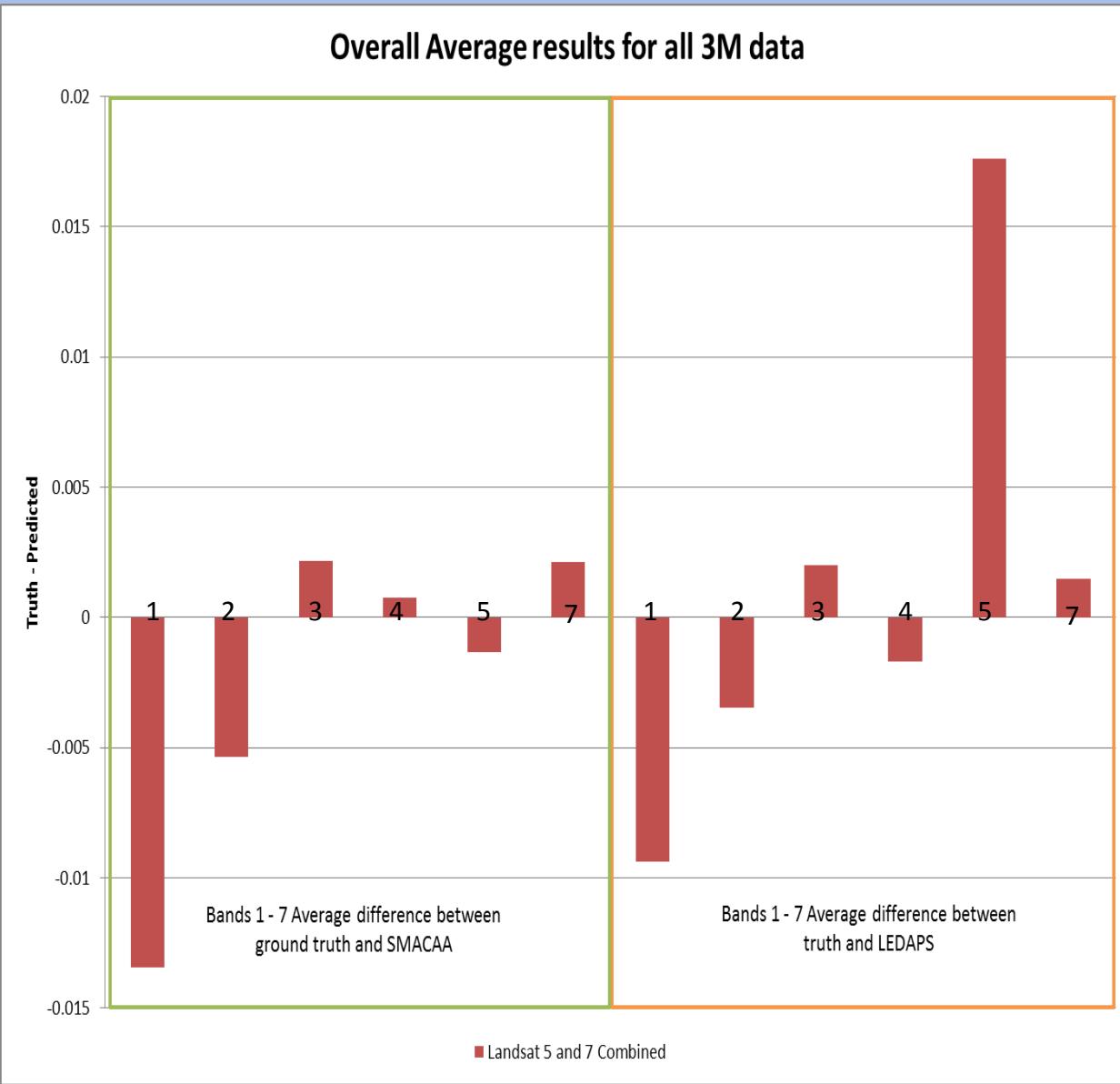


# L1T SR Product vs Truth (Brookings Site)



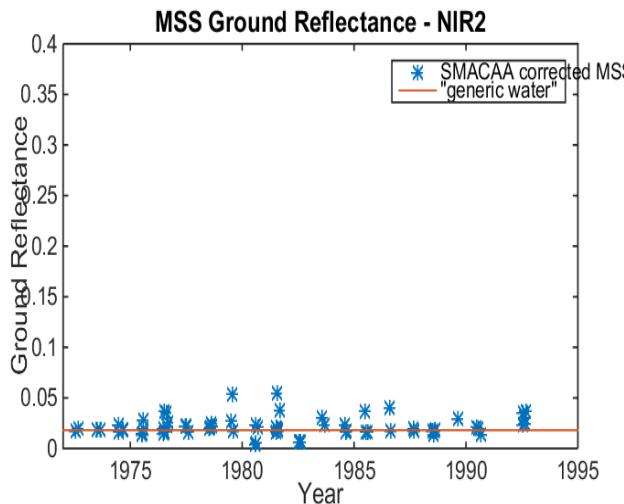
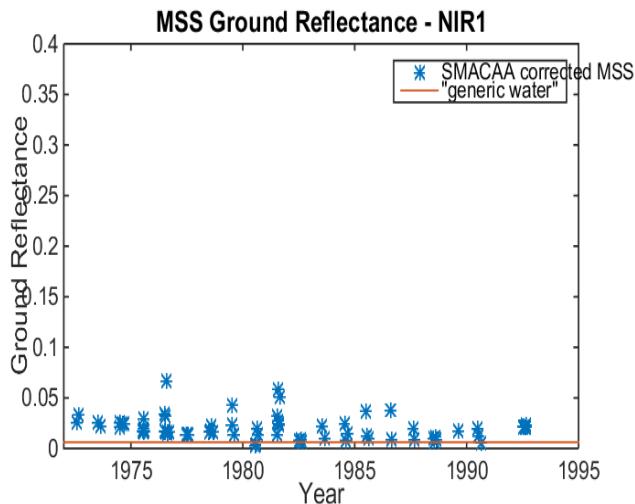
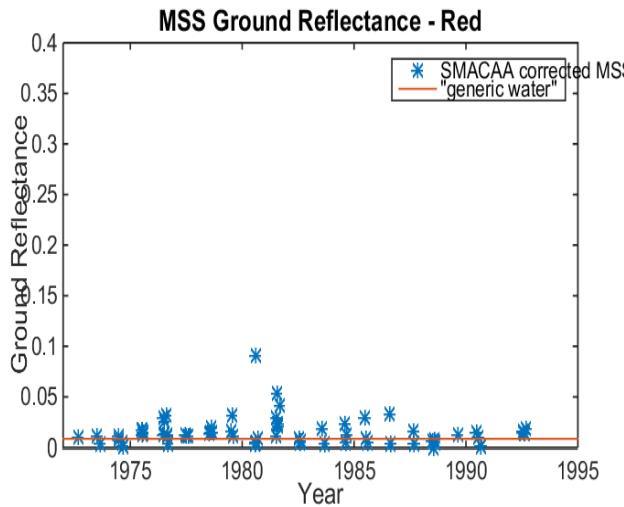
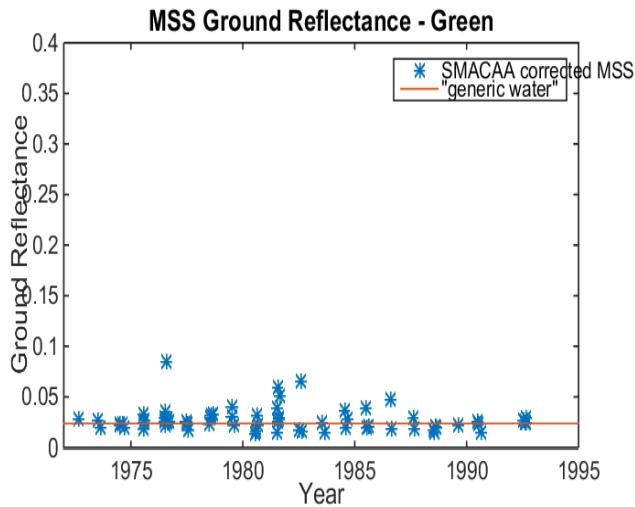
# A-PICS Atmospheric Side: Validation

## SMACAA & L1T SR versus ground truth @ SDSU Test Site



- SMACAA: On average, Band 1 is off by 0.014 units of reflectance and the rest are under 0.005 units
- L1T SR: Less under correction for band 1, but a bit of over correction for band 5; too much “water” being removed?

# A-PICS Atmospheric Side: Validation - Dark Site MSS 1-5 SMACAA Reflectance for Crater Lake

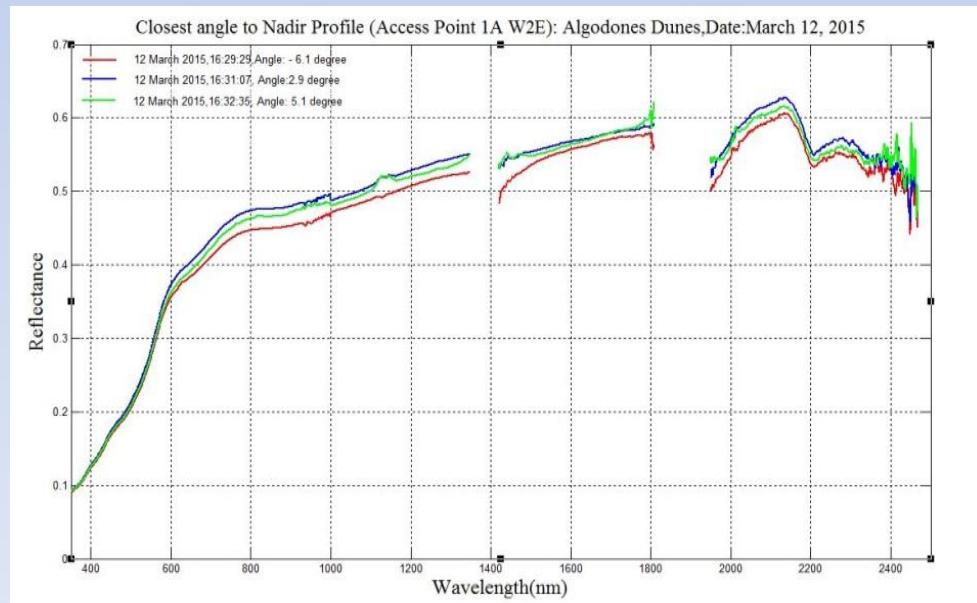


- Due to some work over darker forest sites, with MSS we wanted to ensure the calibration / correction at the low end was correct.
- “Truth” is just standard water reflectance level and does not represent actual ground measurements.
- Check on the atmospheric understanding back through a longer time span ~ 80 images for 20+ years/

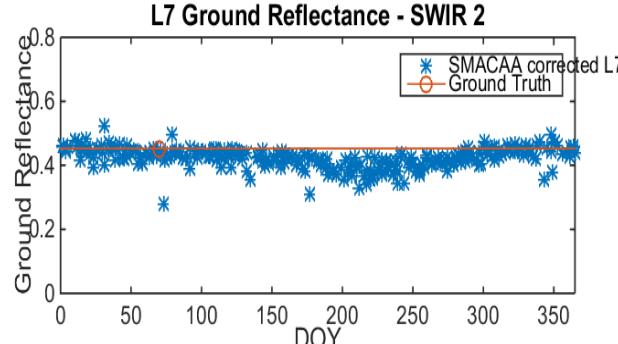
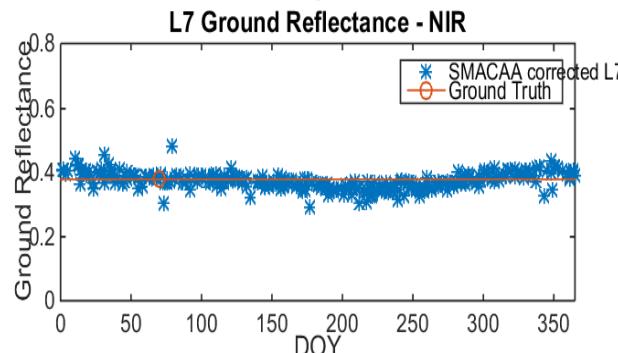
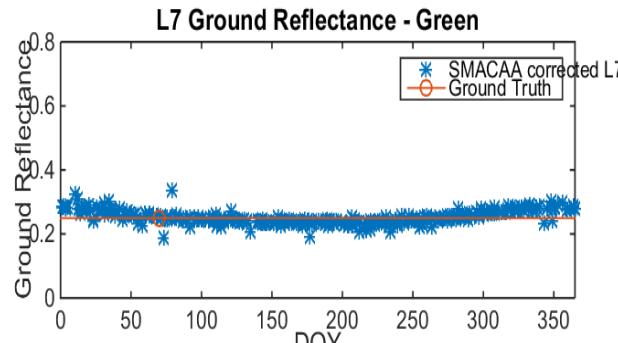
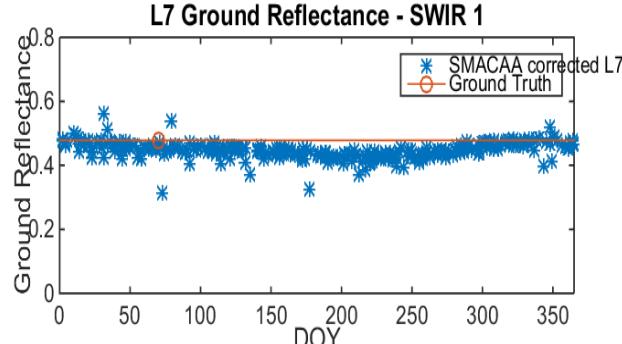
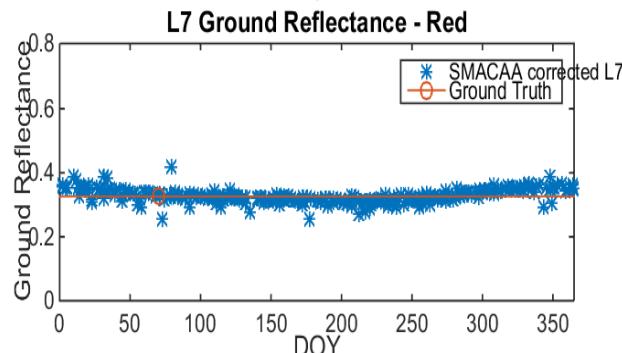
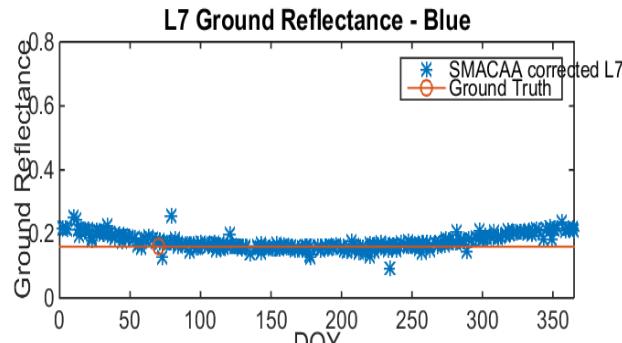
# A-PICS Atmospheric Side: Validation - Bright Site

## SMACAA versus Ground truth @ Algodones Dunes

- With a dark comparison completed, a bright target was chosen, the only bright target we have “ground truth” for is AD.
  - Only have very limited (temporally) measurements of AD, but the assumptions is it's invariant.
- Took all available AD images for ETM+ (348 Images) and OLI (45 Images)
  - Corrected them with SMACAA
  - Compared to ground truth



# A-PICS Atmospheric Side: Validation - Bright Site L7 SMACAA Reflectance for Algodones Dunes

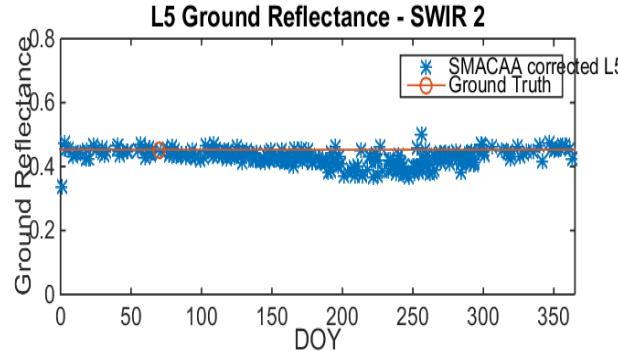
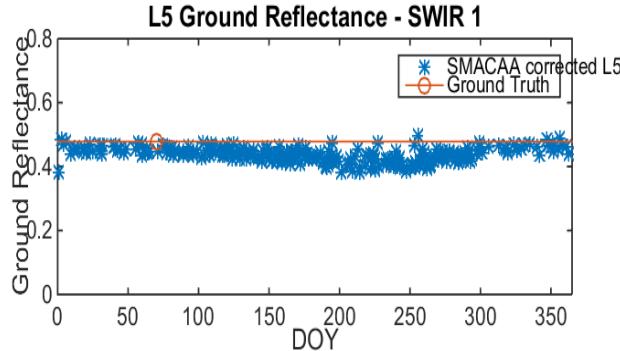
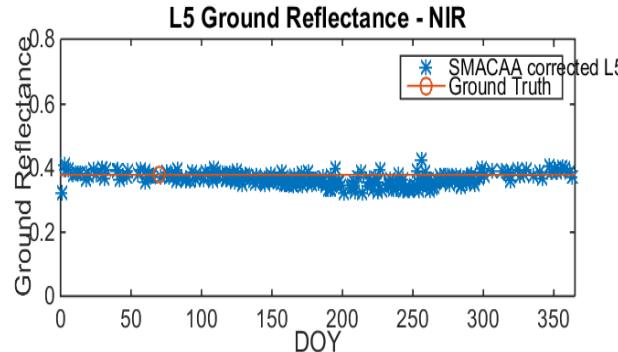
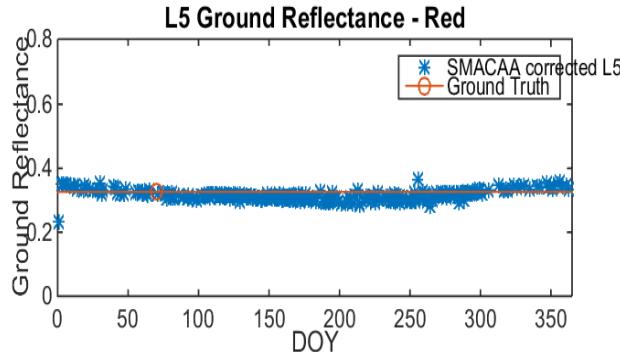
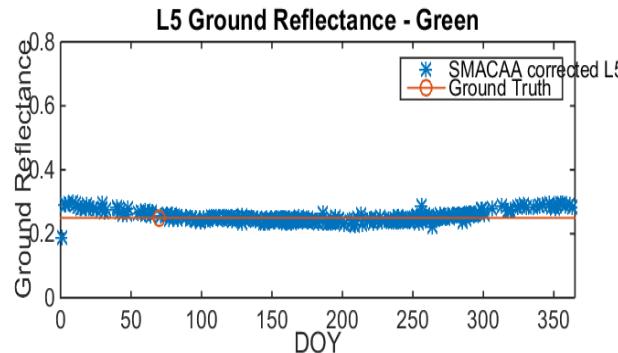
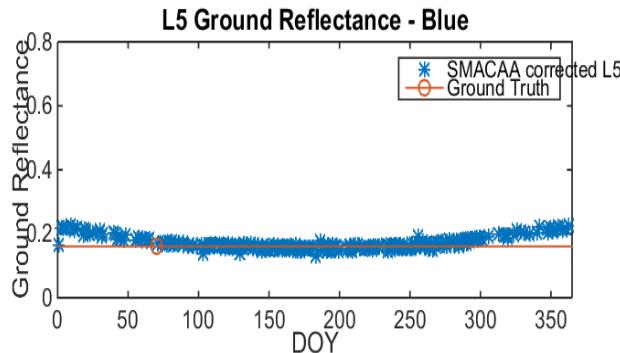


- The red circle around DOY 70 represents the ground truth.

- As before a little under correction for shorter wavelengths

- Yes there is a “smile to the data”, but hold that thought for later (hint: BRDF)

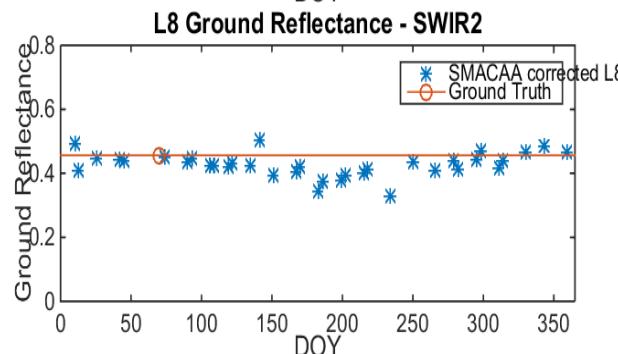
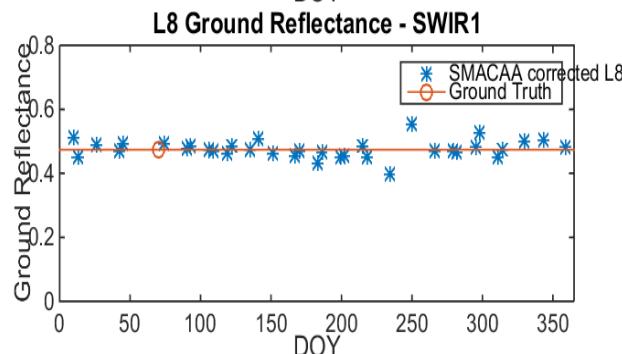
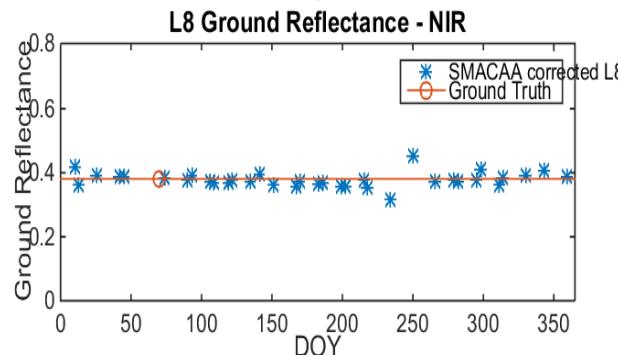
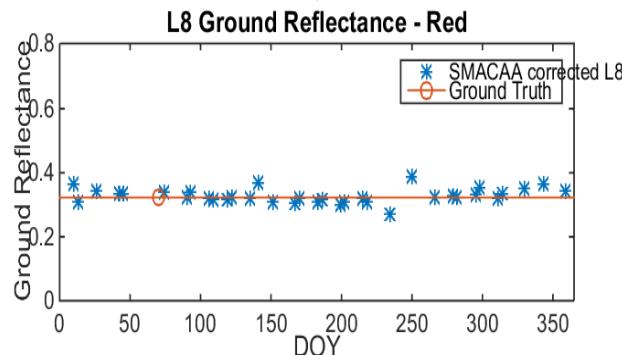
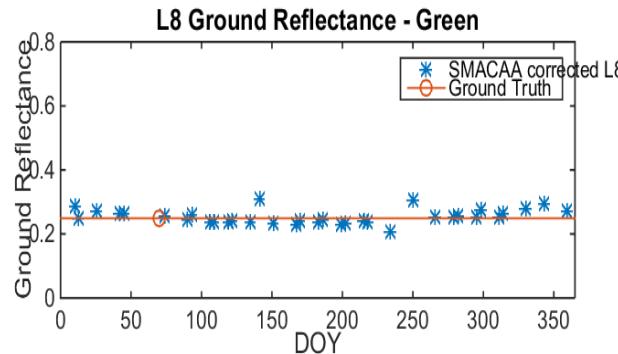
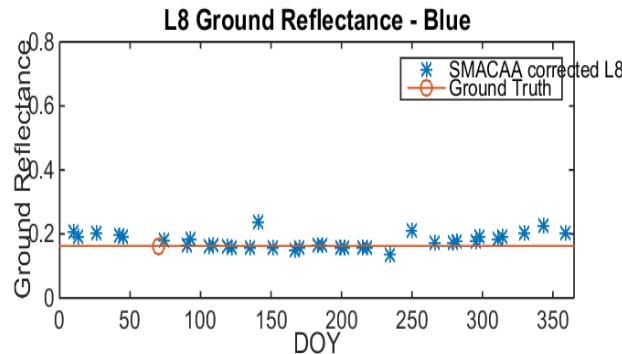
# A-PICS Atmospheric Side: Validation - Bright Site L5 SMACAA Reflectance for Algodones Dunes



The red circle around DOY 70 represents the ground truth.

Same overall shape, little more variation in longer wavelengths

# A-PICS Atmospheric Side: Validation - Bright Site L8 SMACAA Reflectance for Algodones Dunes



The red circle around DOY 70 represents the ground truth.

Same overall profile, with just fewer points

# Sub-Conclusion: A-PICS Atmospherics

- Using sites where the understanding of the ground is high, a check on the performance of the atmospheric correction was evaluated.
- Results indicate some under-correction for shorter wavelengths, meaning an under-estimation of aerosol is producing an absolute error of  $\sim 1.5$  reflectance units.
- Longer wavelengths are within 1.0 reflectance units.
- Overall, the database is accurate and capable of understanding worldwide optical atmospheric correction for 1972- present.

# A-PICS Ground Side: **Algodones Dunes** BRDF Data

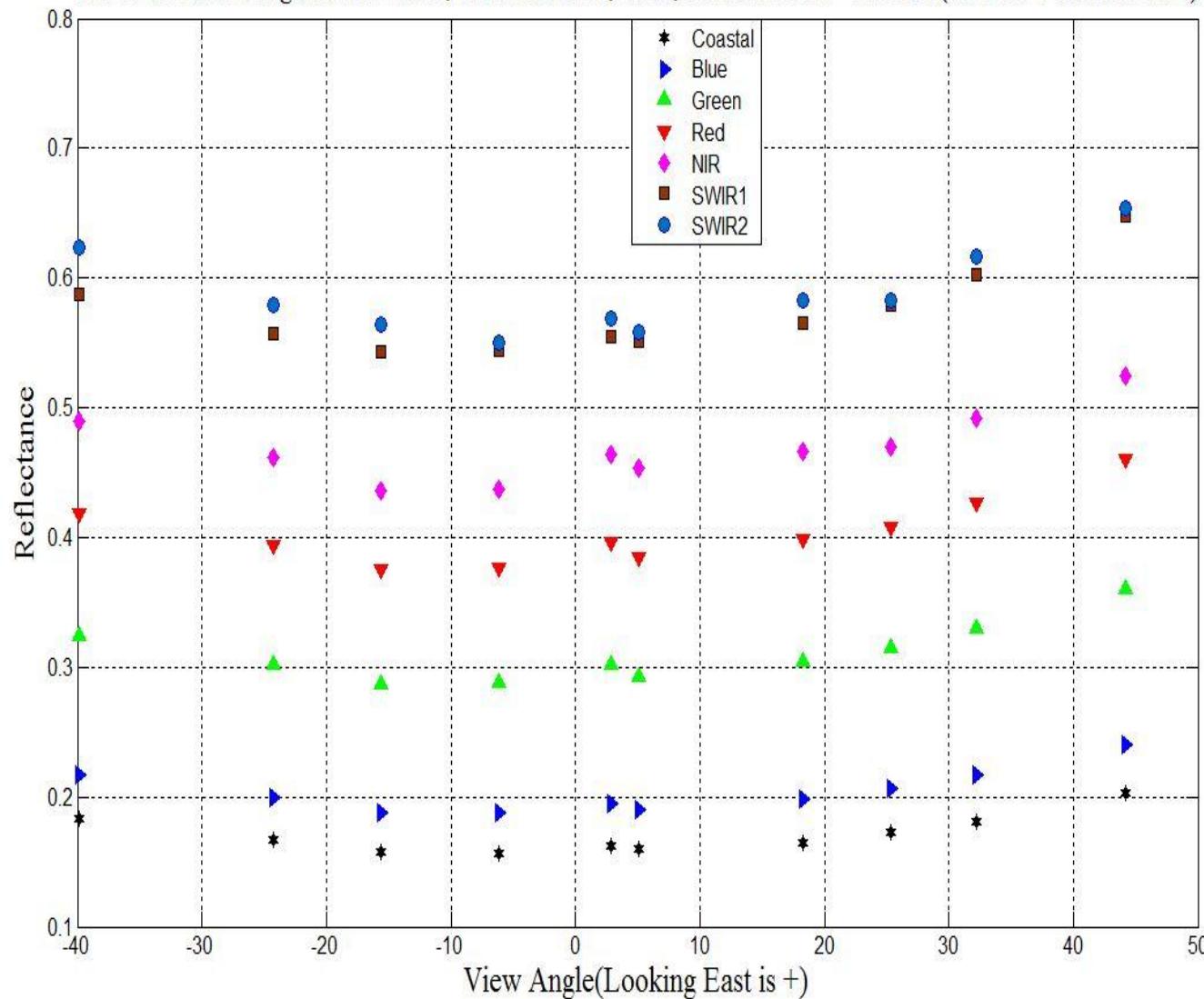
- SDSU collected BRDF from a number of “different” sand categories around base camp (tops / sides / bottoms of dunes).
- The measurements were taken in the principal plane and 90 degrees off principal plane.
- Data is used to “drive model” generation
- Data is also used validate results.
- Key result: A methodology that can be replicated for other PICS that are “less accessible”

# BRDF Of Sand: Algodones Dunes (1A W2E)

Date: March 12,2015, Time: 16:29:29-16:32:47

$S_{\text{zenith}}=59.14^\circ$   $S_{\text{Azimuth}}=116.74^\circ$  -  $S_{\text{zenith}}=58.51^\circ$   $S_{\text{Azimuth}}=117.38^\circ$

BRDF of Sand : Algodones Dunes, Date: March 12, 2015, Time: 16:29:29-16:32:47( Access Point 1A W2E)



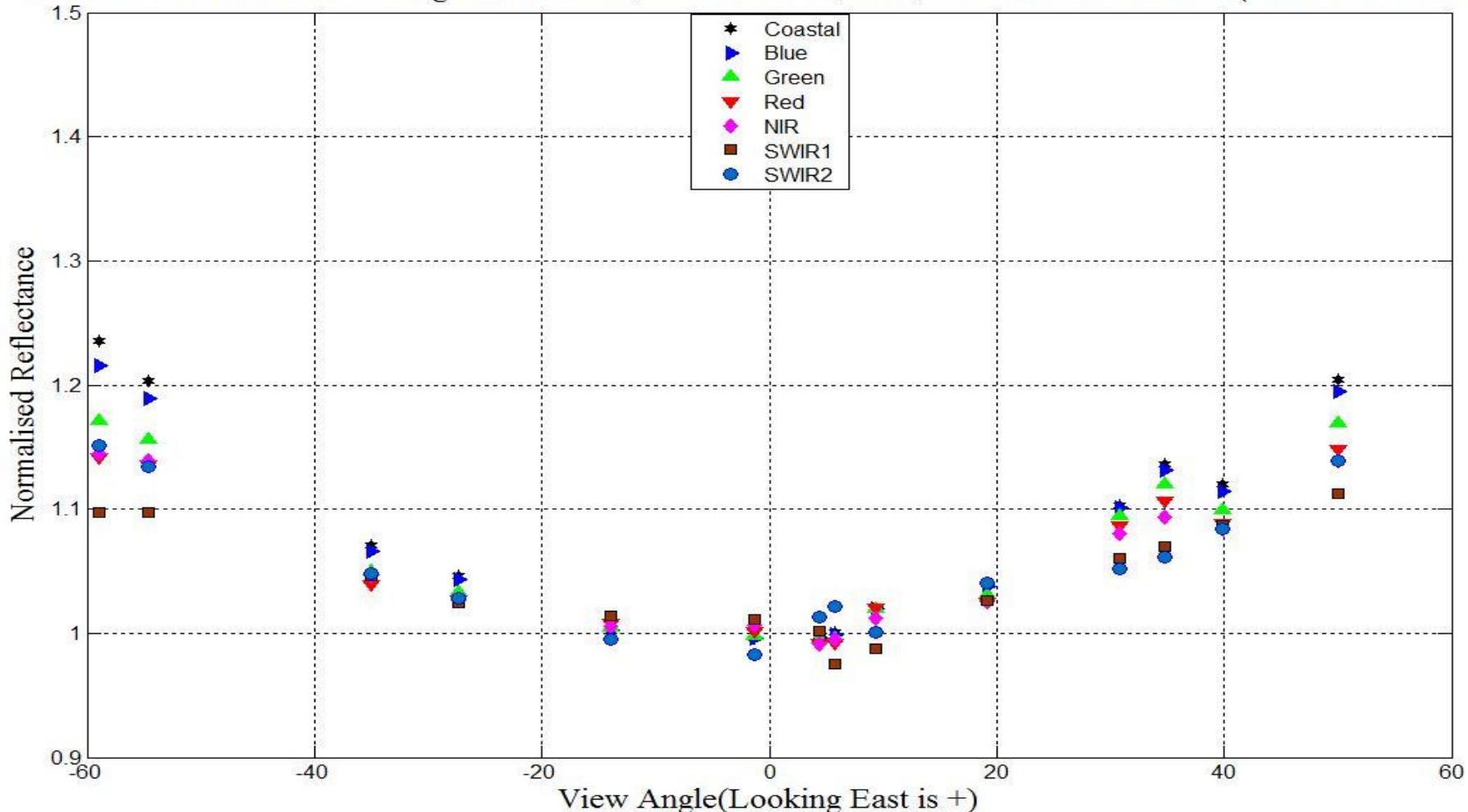
- BRDF as measured by ASD banded to OLI RSRs for point 1A **principal plane**
- Represents 8 in-field measurements taken under the AD campaign
- All bands have roughly the same angle dependences

# A-PICS Ground Side: Normalized BRDF Of Sand: Algodones Dunes

1A principal plane - Date: March 12,2015, Time: 16:35:04-16:38:45

$S_{\text{zenith}}=58.08^\circ$   $S_{\text{Azimuth}}=117.81^\circ$  -  $S_{\text{zenith}}=57.39^\circ$   $S_{\text{Azimuth}}=118.53^\circ$

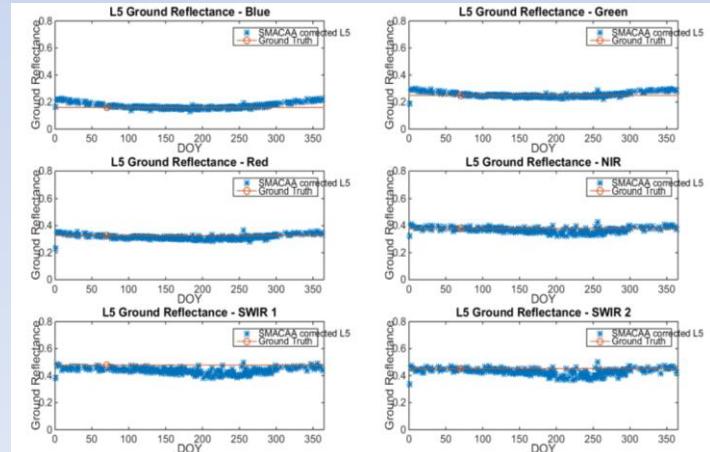
Normalised BRDF of Sand : Algodones Dunes, Date: March 12, 2015, Time: 16:29:29-16:32:47 ( Test Point 1A N2S)



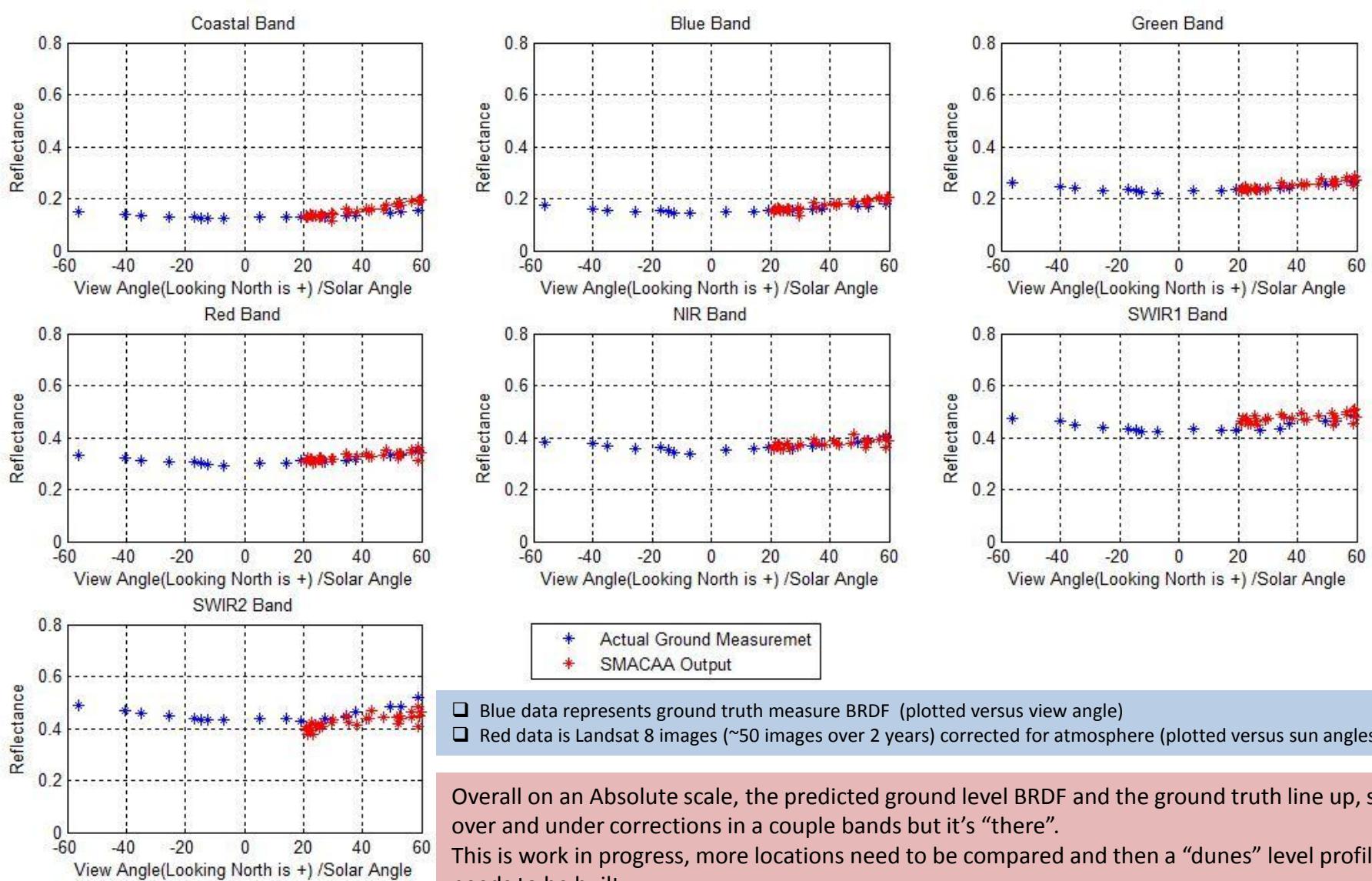
- Data normalized to better evaluate BRDF curve across wavelengths.
- Shorter wavelengths tend to depart from longer at steep look angles.

# A-PICS Ground Side

- BRDF validation is still on going:
  - Need to compare results with other team members,
  - Need to compare results to in-lab measurements,
  - Need to evaluate spatial variations.
- This approach works well for a site that can accessed, but an approach for sites that aren't accessible is required.
- Hint: remember the SMACAA “smile”?



# A-PICS Ground Side: Comparison of Ground Measurement of Sand of Algodones Dunes with output of SMACAA for 1C N2S



# Conclusion: A-PICS

- The data is there to “understand” the dunes, and a methodology to “transport” this understanding to other sites is well underway.
- Need to combine the results of all team members into a consistent “story”. This combined with SMACAA to create a “dune level” understanding, and production of a A-PICS site for Algodones Dunes.
- Currently applying some of the methodology to Libya 4.
- SMACAA and the ground data are meeting in the middle, and the results look spot on.
- Methodology seems to be sound. Once the ground truth / understanding is complete an A-PICS model will be generated, and results compared to other on-orbit sensors.

# Thank You